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Poi Poi Revolution

A real-time feedback training system for object manipulation

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Abstract

The affordability and availability of fast motion cameras presents an ideal opportunity to build computer systems that create real-time feedback loops. These systems can enable users to learn at a faster rate than traditional systems, as well as present a more engaging experience. In this dissertation, I document the development and evaluation of a real-time audio and visual feedback system for geometric poi manipulation. The goal of the system is to present an experiential and objectively superior learning tool when compared to traditional learning techniques in the object manipulation community. For the evaluation, I conduct an experiment that compares the feedback training system with traditional learning techniques in the object manipulation community. The results suggest that the feedback system presents a more engaging experience than traditional mirror feedback training, and conclude that further research is warranted.

Acknowledgements

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1 Introduction

1.1 Overview

Motion feedback training systems are systems that capture a user's motion and provide relevant information back to the user in real time so that the user may adjust his or her motions accordingly. These systems have proven to be useful and applicable to many areas of human conduct, and as motion tracking technology decreases in cost and improves in tracking speed and accuracy, the range of its applications also increases. By providing a user with immediate feedback regarding the user's motions, the user may gain proficiency at a higher rate than otherwise. One area of interest with motion training concerns users interacting with skill based objects. For example, van der Linden, Schoonderwaldt, Bird, and Johnson (2011) constructed a vibrotactile feedback system to teach a user the correct arm positioning for violin playing. The challenge of gaining mastery of skill based objects is difficult, as this task typically requires many hours of practice and feedback from expert instructors. However, lengthy feedback from expert instructors is a rare commodity that most users either cannot afford, or are in a location where no expert instructors are present. One alternative to expert instructors is pre-recorded video training systems that attempt to provide guidance to the general audience. However, video training systems offer no feedback to the user concerning the user's progress, and as a consequence, the user is left to their own discretion as to whether they are performing the correct actions or not. Motion feedback systems offer a solution to the scarcity and cost of expert trainers and to the lack of feedback from video training systems. This is because motion feedback systems will attempt to codify and provide the user with expert training feedback that is necessary for the user to improve the speed of skill mastery. Another advantage of motion feedback systems is that the designer can accentuate important aspects while concealing the non-relevant features from the user. This lessens the cognitive load that the user experiences, and so allows for the user to place more attention on only the important considerations in the training.

One area where motion feedback systems would be highly valuable as a means to teach movement is the performing arts. In the performing arts, there is a subset referred to as object manipulation, where the performer manipulates objects for artistic effect, and the movements performed are typically with reference to a geometric framework. In this context, a geometric framework is to be understood as a geometric shape that the performer moves part of their body along and within to illustrate some or all of that geometric shape to the audience. For example, consider the following figure as an illustration of a geometry overlaid on top of a user, see Figure 1.

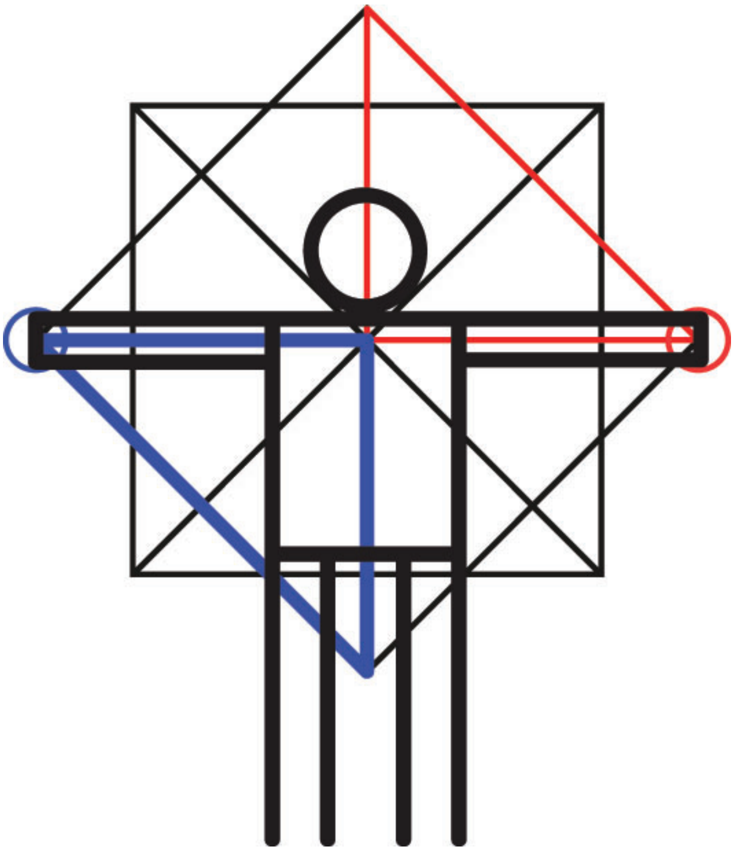


Figure 1: Geometry for an object manipulator.

Another area of interest for motion feedback systems is in physiotherapy. Due to the fact that these systems create feedback loops with participants, and that they can be relatively inexpensive, presents an ideal opportunity for these systems to help with rehabilitation and other kinds of movement training. While this is not the focus of this thesis, it is something that I aim to keep in mind throughout the development of the systems.

In this thesis, I develop a prototype system that tracks a manipulated object in real-time, using an affordable camera. I run an experiment, comparing it to mirror feedback training, discuss multiple measurements for the interpretation of the results, discuss how this reveals important parts of the software, and show what is needed in future revisions.

1.2 Motivation

I have been learning object manipulation in the performing arts for the last four years. In that time I have learned valuable techniques from a vast number of performance and instructional videos on Youtube, and from DVD's. I have also learned from many performers in person, and I have been taught by workshops on object manipulation for the last three years at festivals. This experience has made me deeply appreciate the benefits I have personally experienced through learning this art form and by being connected to the performing arts community. One aspect of object manipulation has intrigued me from the beginning, that is: what are the most efficient and best ways to learn the techniques of the discipline? This is a question that I have applied to my own quest for improvement, and as such, I feel with my experience, I can say confidently that I know the basic types of teaching methods used for object manipulation. Of these types, one may break them into a few different categories, but it is important to note that all are based in a form of mimicry. The first type is learning in person, either in a group or one on one scenario. The student can either be taught in a lesson format where the goal from both teacher and student are the same, that is, for the student to learn the movement. Another way to learn in person is by watching a person perform. It is worth noting, however, that this latter ability is a more difficult skill to acquire than by being taught directly. Indeed, it seems as if one must acquire the concepts before one can adequately mimic the movements viewed. A second type of learning involves watching videos of performers, and watching video lessons. The advantage to videos is that the student can play them as many times as they wish, and also, if they have the technical know-how, they can use applications to show the video down, so that the motions are performed slower than it is possible to perform the movements in person. However, a disadvantage to this type of learning is that the video can't respond to any questions or difficulties the student may have, and in that sense, the student is left to find some other way to come to an understanding. The third type of learning, seems to be based in self practice. One can either do this in real time, i.e., by watching their shadow, or by watching themselves in a reflective surface, such as a window or a mirror. In this case, the student is looking at aspects of their own movements, and are making adjustments based on the information received. This type of learning can also be used to compare how a movement looks as the student performs it with respect to an imagined picture of what the movement ought to look like. An advantage of this type of learning is that it is immediate. There is no delay in seeing one's own movements. It does seem to require, however, an already established conceptual scheme, and an intentional ability to perform some of the movements. In effect, it seems that this type of training can be used more for refinement than for new movement acquisition. A final type of training involves watching self recorded videos of movements by the student, as well as short and long exposure photographic images. Long exposure images allow a student to see the pattern they have performed over a period of time, and as such, these types of images can be used to determine the consistency of one's movements.

From these basic ways of learning information, it is clear that the object manipulation community has advanced at a great rate due to video sharing websites, like youtube and other internet based community forums. However, I believe that some of these training types can be fused together. One way this can be achieved is through a motion feedback system. The rough idea is that, a camera could be use to detect the motion of objects that one manipulates, and could overlay that information on preexisting patterns and movements that a performer or student can learn from. In effect, it would make use of mimicry, because one could see an existing form, as well as having the ability to immediately get feedback on one's own movements with respect to that pattern.

1.3 Thesis Goals and Contribution

Currently there does not appear to exist any real-time feedback training systems for object manipulators. In that respect, this system will be the first of its kind. I plan to use the technology developed in the system and continue work on it after the thesis is complete. In that respect, affordability is an important factor. The cheaper a system can be built, the wider the audience that can use such a system.

One of the design objectives is that I want to be able to build this system so that it is affordable by artists, and as such, I would like to make it as cheap as possible. This excludes expensive motion capture systems and camera systems that already exist and could have been made to fit this type of purpose.

- Develop a feedback system that is aesthetically pleasing to use.
- Allow the system to be extendable.
- Attempt to use inexpensive hardware so that the system can be widely used.
- Validate the utility of the system by way of an experiment.
- Add information about object manipulation to the collective body of knowledge.

1.4 Thesis Organisation

The thesis is divided into sections that may not accurately represent the chronology of events, but will allow for clear logical progression of ideas, as well as the presentation of different pieces of work. The thesis fits a usual format of Introduction, Background, Methodology, Results, Discussion, Conclusion, and Recommendations for Future Work, but it also includes one section on field testing that was conducted, as well as a detailed account of the development process, and insights gains from that process.

The variety of manipulated objects is large, but some of them include poi, staff, juggling balls, rope dart, club swinging, and meteor. In my research I intend to build a system for poi manipulation but many aspects of the research will be generalisable to object manipulation. At this stage it will be useful to consider what poi actually is, and why it is a challenge to learn. In poi, the user holds a rope - referred to as a tether - in each hand. At the end of each tether is a weight, which usually happens to be a ball of a variable weight and size. See Figure 20 for an example of contemporary poi design.

The user will learn to spin the poi heads along the tether in a variety of different directions and different relational timings to each other. They will also learn to move the spinning poi around their body, and to move their arms while the poi are spinning so that the poi heads meet at certain points around the user's body. Traditionally, poi originates in Maori culture and was used as part of Maori dance. In its contemporary form, poi makes use of geometry as a means of connecting many predefined patterns together, as a way of assembling complex patterns from simple movements, and as a guide to present aesthetically pleasing patterns. The patterns constructed may be understood in two ways: the first way concerns the patterns which the poi heads are making in space.

The second way concerns the patterns the hands are making in space. Furthermore, there exists a priority of hand movements to poi head movements, such that, as long as the user knows the direction in which the poi are spinning, then the hand paths become the essential characteristic that the user must pay attention to. If the hand paths are moved in precise ways, then the poi will accentuate those paths.

Now, it is by no means an easy feat to gain proficiency with manipulating poi for artistic purposes. For one, it requires the user explore the range of possible movement that the object they are manipulating permits. It also requires that the user adopt a playful, childlike disposition towards the object. Mistakes in this context should therefore be viewed as a helpful guide. Moreover, the sphere of possible poi patterns is so large, that it is a practical impossibility to learn every trick. However, the number of tricks that users who spin poi today is far larger than it was a mere 10 years ago. Part of the explanation for this is accounted for by the rise of online video sharing sites like YouTube. Due to the fact that poi is a visual art, tricks may be shared to other poi users through online video sharing. Online communities have also been established which bring together poi users from a wide range of different locations around the planet.

One of the main problems with online video sharing is that it does not provide the watcher with any active feedback. If the watcher is watching with the intention of learning some new poi tricks, they will in general have to re-watch the video many times and at different speeds in order to fully comprehend and be able to mimic every part of a complex pattern. This is similarly true for poi DVD's, such as the Encyclopoidia Volume 2 (Moore & Everett, 2009).

If one considers the task of learning poi with feedback, there currently appears to be only two main ways in which a poi user can receive active feedback other than from the poi itself. The first way requires the poi user watch their own movements using a mirror. This type of feedback is immediate, and it does allow for quick adjustment of patterns. However, it provides no extended information about the geometric shape they are making patterns within, whether they are aware that they are repeating the same pattern a specific number of times, and provides only visual feedback. Furthermore, it does not allow one to easily mimic the pattern that another is making. The second way is the expert guidance of an instructor who has taught many poi users before. They understand where most users will have difficulty, they can stand in front of the poi user and take them through in a step-by-step fashion, all of the parts of the movement, they can answer questions the user may have about the movement. The instructor can also teach by means of direct haptic feedback, that is, by guiding the user's arms and hands into the position they require directly. However, this type of training, while ideal, is largely impractical due to the need for one-on-one training, and the time demands for both the trainer and the user. Therefore, I propose that a motion feedback training system for geometric poi manipulation would be an ideal compromise between one-on-one physical training and video or mirror training. The goal would therefore be to construct a system that allows one to learn at a faster rate than both mirror training and video training. Also, by using a computer motion tracking system and output system it will be possible to convey more types of feedback than would otherwise be possible. It would have the advantage of directing the user's attention towards the essential aspects of their poi spinning so that they may turn non-conscious movement into intentional movement.

2 Background

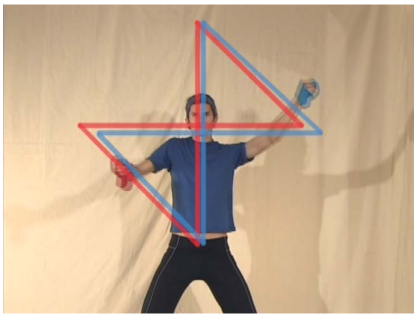
In this section I provide a literature review of feedback training systems and provide a necessary background of poi manipulation. This will enable the reader to appreciate the design decisions made thereafter. I have surveyed a large amount of literature, but the number of relevant papers for this type of performance art is very small. Therefore, I have had to draw from sources outside of academia, as well as refer to my own experience as a professional object manipulator and performance artist. I have also made use of some examples of the techniques used in some of object manipulation DVD's.

In order to discuss the previous research relevant to this thesis topic, I have divided the background research into two distinct sections. The first concerns poi and geometry, the second concerns computer motion training systems. It should be mentioned that this section does lack the authority that is created through academic references. The truth is, in academia, there is next to no research on the performance art of object manipulation.

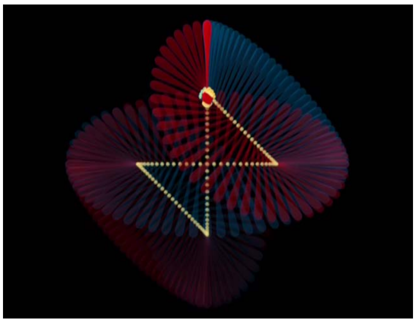
2.1 Object Manipulation

2.1.1 Poi

Poi consist of a weight and a tether. A user holds the tether and moves the poi around so that the poi creates aesthetically interesting movements. Poi as a pastime and performance prop has its origins in Maori culture. However, it is only with contemporary poi that the geometric influence can be easily discerned. Consider the following example as evidence for this claim. In 2009, Zan Moore and Alien Jon released a DVD titled 'Encyclopoidia Volume 2'. This DVD attempts to codify and critically analyse poi movements into a hierarchy of simple movements to complex movements which are wholly constituted by the simple movements. In order to teach using the method of hierarchical analyse, Moore and Alien make use of graphical animations of the poi moving in space, spoken explanations, video without computer graphics overlaid, and video with computer graphics overlaid (Moore & Everett, 2009). The following two figures 2.1.1 illustrate both overlaid graphics as well as computer generated graphics.



(a) Overlaid Geometry for Poi Handpaths



(b) Computer Generated Geometry and Pattern Effects

Figure 2: Different types of teaching techniques, (a) and (b) for geometric poi manipulation.

Together, the different forms of visual and audio explanation offer a compelling way to teach a very complex array of poi patterns and movements. However, due to a limitation of the medium, there can be no direct feedback as to whether the user is identifying the essential characteristics of the movement, nor is there any feedback concerning the difficulties the user may face in learning the movements. Therefore, while the DVD presents a conceptual language as a usable tool-set to the user, it does not offer essential training feedback to the user.

Other DVD's for poi manipulation are also available. One such DVD is Partner Poi by Crew (2010). It covers some of the theory and techniques used in partner poi movement. Partner poi is where multiple participants use poi and perform movements that weave the poi through each other's space, or use multiple sets to create more complex and visually appealing patterns. The DVD makes use of many different camera perspectives to help teach the various techniques and tricks to the watcher. An example of this can be seen in the following figure 3.

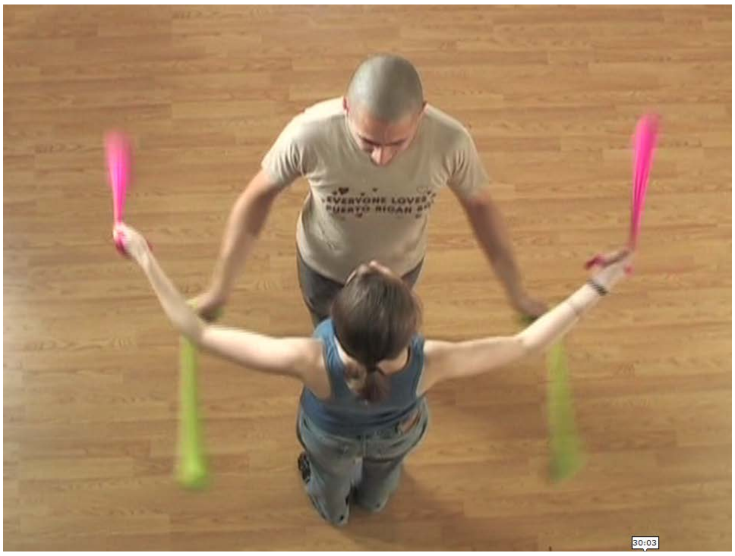
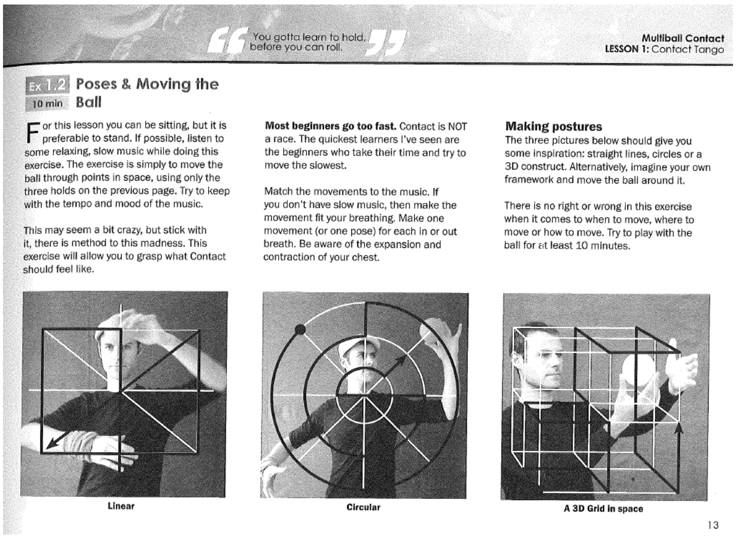


Figure 3: Partner poi camera perspectives

2.1.2 Other kinds of props

Other kinds of props used by the object manipulation community includes staff, double staff, rope dart, umbrellas, hoops, isolation hoops, and clubs. This is by no means exhaustive. In fact, new objects can become objects intended for manipulation simply by taking those objects and seeing they can be used given the space they exist within.

One such example is a book called Multiball Contact by Batchelor (2007). This book covers manipulation tricks and techniques for contact juggling. Contact juggling involves keeping a ball in contact with one's body, rather than traditional juggling where one would be throwing the ball away from one's body. The book makes use of many different images from different perspectives to help illustrate what the tricks look like from the performers perspective, what the easiest perspective to learn the core concept is, and what it looks like from an audiences perspective. The book also makes use of geometry to help illustrate that, if one chooses, one can manipulate the ball with respect to these geometric shapes (Batchelor, 2007). For an example of this, consider this figure 4.



“You gotta learn to hold, before you can roll.”

Multiball Contact
LESSON 1: Contact Tango

Ex 1.2 10 min **Poses & Moving the Ball**

For this lesson you can be sitting, but it is preferable to stand. If possible, listen to some relaxing, slow music while doing this exercise. The exercise is simply to move the ball through points in space, using only the three holds on the previous page. Try to keep with the tempo and mood of the music.

This may seem a bit crazy, but stick with it, there is method to this madness. This exercise will allow you to grasp what Contact should feel like.

Most beginners go too fast. Contact is NOT a race. The quickest learners I've seen are the beginners who take their time and try to move the slowest.

Match the movements to the music. If you don't have slow music, then make the movement fit your breathing. Make one movement (or one pose) for each in or out breath. Be aware of the expansion and contraction of your chest.

Making postures
The three pictures below should give you some inspiration: straight lines, circles or a 3D construct. Alternatively, imagine your own framework and move the ball around it.

There is no right or wrong in this exercise when it comes to when to move, where to move or how to move. Try to play with the ball for at least 10 minutes.

Linear

Circular

A 3D Grid in space

13

Figure 4: Contact Juggling geometries used in the book Multiball Contact

Another DVD, titled Staff Manipulation by Pike and Wilson (2008) also makes use of geometric shapes to help illustrate movements, and to show how movements can be made with respect to particular geometries. This DVD teaches a range of different kinds of staff manipulation, from basic weaving patterns, to contact staff - where one is no longer holding onto the staff, rather the staff being supported by some part of the body, and is sometimes moving along the body - and double staff (Pike & Wilson, 2008). The following figure 5 shows an example of a basic geometry used for staff manipulation.

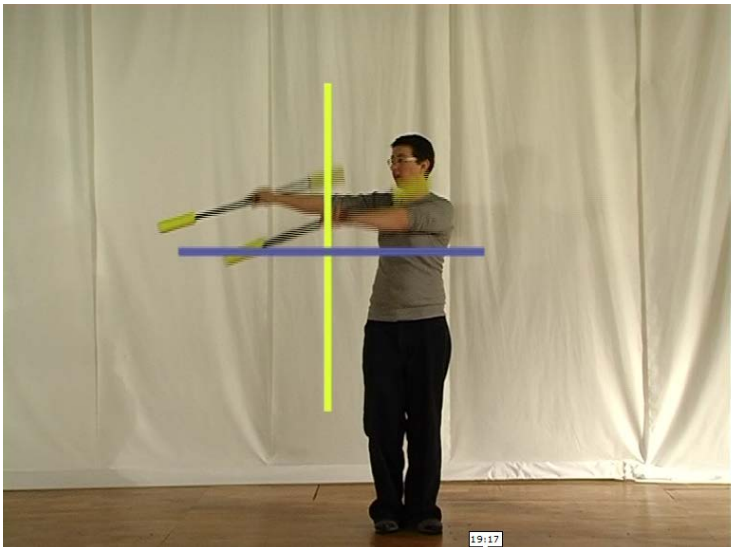


Figure 5: Example geometry for double staff manipulation

It is also important to mention the performance artist, Michael Moschen. Moschen is a performance artist and juggler who received a fellowship from the MacArthur Foundation. His use of a wide variety of different kinds of objects, and his exploration of space and time with these objects (Chartier & Moschen, 2008), has served as a great influence on the object manipulation community.

2.1.3 The community

The object manipulation community establishes itself in many domains. For example, there are strong internet communities devoted to sharing object manipulation concepts, by way of video sharing sites. There are also keen discussions about the linguistic and conceptual understanding needed for certain types of movements. Geometry plays a strong role in these discussions, because it can be used as a foundation for the movements.

2.1.4 Training, practice and play

In order to train using poi, there are a few different approaches. One can train by oneself, make use of videos onlines, or existing DVD's. Another option is for one to just explore possible movements with the object. In this way the object's affordances can be slowly revealed. The training methods that one can use on oneself involve using mirrors to see the patterns one is creating, recording video to watch oneself to watch at later dates. One can either focus on refining existing moves or try to come up with new concepts.

When two or more object manipulators are together, then it is possible to share ideas between one another through demonstration. In the demonstrations, there is either a prerequisite linguistic understanding, or there are attempts to convey the necessary concepts in order to understand the intention of the movement.

2.1.5 Transferring frameworks, teaching, and sharing

The community shares different modes of communication. One prominent form is by way of video demonstrations online. Popular sharing sites, such as www.youtube.com are used by the community to help share ideas. Other social sharing sites, such as www.facebook.com contain many groups that focus on specific types of object manipulation. Some videos are designed to be a demonstration of a sequence of movements, and to be a promotional video for a performer or performers, while others can focus on very specific types of movements, and the logical breakdown of those movements into parts, so that one watching may more easily acquire that concept and technique.

2.2 Motion Training Systems

There has been extensive research into the use of motion feedback systems for training and educational purposes. One paper that nicely corresponds to the type of research I intend to do is by Chan, Leung, Tang, and Komura (2011) titled 'A Virtual Reality Dance Training System Using Motion Capture Technology'. In it, a dance training system is presented where a student learns dance by imitating a virtual teacher's movements. The key relevance this has with what I plan to do is that the player learns by imitation. In effect, it is through mimicry that allows the user to learn. It is found that the system constructed better affords the student's capacity to learn than video watching techniques (Chan et al., 2011). The value of this research to the intended thesis is that it provides immediate visual feedback to the student in the form of a virtual representation on a screen. By investigating this research I hope to gain insight into the prototype design phase of my thesis, as well as better evaluate the utility of my prototype. However, the research neither concerns itself with moving within or along predefined geometric shapes, nor is it suitable for use with external props, such as poi.

A similar, though less evaluated system is presented by Hachimura, Kato, and Tamura (2004) titled 'A Prototype Dance Training Support System with Motion Capture and Mixed Reality Technologies'. In this paper, the researchers investigate the use of HMD technology for dance training. Through the user evaluation conducted, it was brought to their attention that participants identified that accuracy of represented motion is very important. Furthermore, the weight of HMD technology is also important to consider as a dancer requires as much freedom of movement as possible (Hachimura et al., 2004). This research is interesting as it explores a number of different modes of representation, such as wire frame, solid, solid with wire frame and solid with texture. However, as in the last example, the research does not consider movement in terms of geometric shapes, and it does not look at movement with physical props.

Another paper of interest that investigates physical training using motion feedback is 'Training for Physical Tasks in Virtual Environments: Tai Chi' by Chua et al. (2003). In it a wireless prototype system for Tai Chi is constructed. This system makes use of an immersive virtual environment where the student's full body is tracked and rendered in the environment. It is of particular interest that in the study, the researchers tested the placement of a virtual instructor in a variety of different positions – such as having the instructor's body superimposed over the student's virtual body and placing the multiple copies of the instructor around the student's body – and found that each position was not significantly better than the other. The value of this research insofar as it relates to this thesis is that it presents a 3D virtual environment for learning, and draws upon the idea of learning through mimicry. It will be useful to investigate this paper further when I consider the use of HMD's and video projector based displays. However, this research does not attempt to teach geometric movement or the usage of props to the student.

Along with this is a paper by Sziebig, Solvang, Kiss, and Korondi (2009) called 'Vibro-tactile feedback for VR systems'. This looks at making an affordable vibrotactile glove that provides sensory feedback from a virtual environment. The interesting factor of this paper with regards to my research is the fact that the emphasis has been placed on affordability (Sziebig et al., 2009). This is surely an important factor to consider, as a system that is cheap can be used by a far greater proportion of the population. The researchers also made use of the .NET programming environment and the java environment.

One paper by Baca and Kornfeind (2006) titled 'Rapid Feedback Systems for Elite Sports Training', suggests that by placing sensors within the tools used by sport practitioners, the practitioners are able to access more relevant information than they would otherwise. In effect, it makes a case for these types of systems, and also suggests that it could be used by sports commentators, so that they may visualise the type of movement performed by the practitioner (Baca & Kornfeind, 2006). The paper considers and discusses the development of a feedback system for table tennis, for rowing and for biathlon. They make a point that the measuring devices used did not get in the way of the practitioners. They also mention that easily understood graphical user interfaces are essential as the practioners should not be considered computer experts. They also make the keen observation that some practitioners became more competitive by using the data generated from the system. Cost of the system is another factor that they discussed, and it appears that the measurement and feedback tools they constructed were substantially cheaper than existing measuring devices.

Feedback systems have also been designed to help patients with walking difficulties. One such paper is 'Visual feedback system showing loads on handrails for gait training' by Sabe, Hayashi, and Sankai (2012). In this paper, the researchers attempt to improve a patient's walking ability by visually indicating the amount of weight and pressure on the handrails for a walker. Their aim was to reduce dependence on the walkers by slowly reducing the amount of weight that the patient ought to place on the walker over time. The primary interest of the paper seems to be concerned with imbuing the patient with the awareness of how much weight they're placing on the walker (Sabe et al., 2012). This paper applies to my research insofar as it provides visual feedback from a haptic source. In my research I plan to create an analogue of physical motion and represent it visually. Therefore, this research is an example of this kind of modality transfer working. Moreover, the test it performs has two main conditions: feedback and no-feedback. The no-feedback gives no indication to the patient about the force applied to the walker, while the feedback condition uses the screen to visually indicate force. A t-test was used to compare the significance of the results.

A similar paper to the one just mentioned investigates 'Real-time feedback of body center of gravity for postural training of elderly patients with peripheral neuropathy', and is authored by (Wu, 1997). The feedback system developed from this research provided visual feedback based on a patient's center of gravity. This system measured the angles of the knees, and hips relative to the feet, and from that inferred the position of the center of gravity. It is interesting to note that the study performed using this system involved measuring patients over multiple visits, and as such, it can be considered a longer study. It was also noted that in related studies for this type of feedback training, the participants, after having completed the trial, showed a decrease in their improvement (Wu, 1997). This is to say, they went back to the state they were on originally, or at least close to it. The important factor here is that, the participants need to incorporate the training system into their exercise, otherwise the effects are negligible over time.

Another paper interested in the financial side of feedback systems is 'Reducing error rates with low-cost haptic feedback in virtual reality-based training applications' by Jiang, Girotra, Cutkosky, and Ullrich (2005). In it, the researchers used an existing video game engine, usb vibration and force feedback devices to help assist subjects clear a building. The results showed that the feedback resulted in fewer errors and completed some tasks at a faster rate (Jiang et al., 2005). Now, it is also interesting to mention that the study used 12 participants and that there were 3 conditions on the experiment. This may prove useful in designing an experiment at a later stage in the thesis, as it sets some rough numbers for an experiment concerned with comparing an existing type of training to a newly developed kind of training system.

It is also worthwhile to consider the paper 'The Design of a Rehabilitation Training System with EMG Feedback' by Guangji, Li, Dengrong, Fan, and Haijun (2012). This system uses a device that can measure muscle intensity and fatique using sEMG signals. A graphical representation was made from the information in real time and presented to the participants. While the focus of the paper is on the technology, not the patients, it is interesting to note that they think this type of information can be used to create exercise and movement programs (Guangji et al., 2012). Of course, this seems very reasonable. If the information is available, and it is relevant to a participant, then, combined with a suitable theory that indicates an ideal, then the participants can work towards that ideal. In my research, it may be useful to consider how the information captured could be used to create movement programs to improve upon problems areas for a whole domain of movements.

One paper I would like to pause on for a while, as I believe it more closely resembles the type of research I am pursuing than some of the others, called 'Seeing sound: real-time sound visualisation in visual feedback loops used for training musicians'. This paper looks at the traditional way musicians improve their musical ability: by practice and by being given verbal feedback from experts. It takes this form of training, and looks at taking some of the characteristics from that type of training, and then incorporates it into a visual feedback application that instructs the musicians in real-time. This resembles my work insofar as I am interesting in exploring existing training techniques in the performance art of object manipulation, specifically with poi, as well as looking for a way to display that information to a user, so that they may experience the work in a new way. Another factor that goes without saying is its potential as a training system for artists. Now, one of the things mentioned in the paper is the fact that it is real-time. A consequence of a real-time system is that it must respond near-instantaneously based on a limited dataset (Ferguson, Vande Moere, & Cabrera, 2005). It needs to show variance over time, as well as small changes that happen abruptly. Both of these points are quite important for my feedback system, because they apply almost directly. Another point raised in the paper is that a level of interpretation is required in order to understand the information from within the feedback loop, and that this information cannot be too cognitively challenging to decode (Ferguson et al., 2005). This applies to my thesis work as well: because the performer will be making movements with the poi at a fast rate, they require feedback that is immediately helpful, as well as the fact that it is easy to decode the information. This suggests I may need to investigate visual aesthetics more than mere numbers. They used filtering algorithms to isolate parts of the sound, and then further algorithms to pick out the important aspects so that they may be analysed. The environment in which this was done was called Max/MSP - it is a kind of visual programming language for audio. An important point to make from this kind of research is that a feedback loop of this kind generates content - that is, it's not a simple static thing that one must adhere to, rather, based on the information received, and understood, the musician may then choose to intentionally adjust the visualisation by altering the sound.

The papers I have discussed so far have focused their attention on providing close analogues of the environment which humans normally experience when training tasks are concerned. A slightly different paper by Majoe, Kulka, and Gutknecht (2007) titled 'Qi energy flow visualisation using wearable computing' instead focuses its attention on representing the abstract notion of energy flow to users in order to help teach Qi. In it, they investigate a first person perspective representation and a representation of the user as a ball moving through a martial landscape. The guiding motivation for more abstract forms of representation is that the researchers did not want to overstimulate the mind, because the point of Qi training is in part to relax the mind. They also experimented using 3D sound only and found that some users were able to perform just as well in the required task than users who received both 3D sound and visual feedback (Majoe et al., 2007). This paper is particularly interesting for my research because I wish to experiment with sound as a feedback mechanism for movement. Moreover, the emphasis on abstract representation is also in line with my research intention. However, what this research does not do is look at movement in terms of geometric shapes, and it does not look at training with poi.

A valuable paper by van der Linden et al. (2011) explores the use of vibrotactile feedback for novice users learning violin bowing technique. Typically, the task of learning correct posture and arm position for violin bowing takes 700 hours practice to gain basic mastery. Therefore, it is a task of considerable challenge. The system presented by the researchers attempts to improve the speed at which one gains this basic mastery. A study was conducted using the system that showed that of a control group who received no training and a group who received vibrotactile feedback training, that the group who received the training did improve at their bowing technique, while the control group showed no sign of improvement (van der Linden et al., 2011). Moreover, this paper is interesting to my research for it argues that vibrotactile forms of feedback is advantageous over other forms of feedback when the task to learn is concerned with movement training.

Another paper concerned with haptic movement training by Lurie, Manuel, and Shull (2010) explores the use of real-time haptic feedback for gait retraining. In the paper, the researchers investigate the role of attention using haptic feedback and find that even though the participants that didn't pay full attention to the experiment task, they still showed signs of improvement using the haptic feedback system. However, the participants that did pay full attention showed a greater sign of improvement when compared with the participants who did not (Lurie et al., 2010). The paper, therefore lends further credence to the importance of haptic feedback when users are challenged with motor training tasks.

Of the research papers, books and DVD I have discussed in this section, none have addressed the issue of geometric poi training using real-time motion feedback. While there exists elements of my intended research in each of the reviewed works, there is nothing that unifies them under a single system.

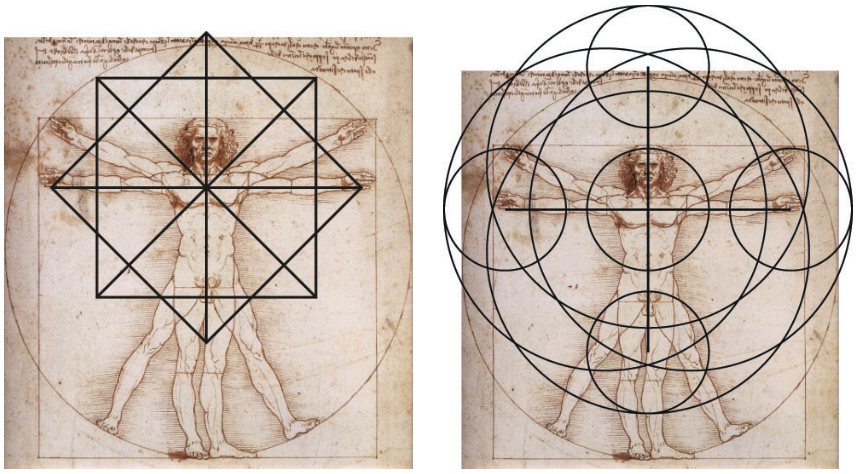
3 Design and Prototyping

3.1 The problem domain - the intended audience

The intended audience for this system are object manipulators using poi. I will in the design of the software, attempt to cater to more types of objects, but poi will be the primary focus. Further to this, because my domain is for people who already use poi, then it is understood that potential participants in the study I conduct later will already have the requisite knowledge to do basic poi manipulations.

3.1.1 Domain Findings

In poi, there are geometric shapes, sometimes called, frameworks, which object manipulators use in order to create aesthetically pleasing patterns. One aspect of an aesthetically pleasing pattern is in its geometric accuracy. Consider the following figure as an example of a linear geometry used by object manipulators.



(a) Linear Geometry for Poi Object Manipulators (b) Circular Geometry for Poi Object Manipulators

Figure 6: Linear (a) and circular (b) geometries used by poi object manipulators.

The linear geometry figure, see 6(a) shows how the geometry is top heavy (that is, it does not include the legs as movable features), and is designed so that the manipulator uses their hand to trace out part of or the entire geometric pattern. Repeating parts of the shape can be thought to be smaller patterns in themselves. However, poi will often focus on making circles. However, in the circular geometry image from the same figure, it can be seen that by using the body's natural geometry of arm length and symmetry that one can create circles in many different positions. The relationship between the positions and the time in which they are made aids in its aesthetics.

3.1.2 Prototype Requirements

From the previous sections, I have selected some important factors that will be used in the design of the prototype.

- Capable of real time tracking.
- Use affordable technology.
- Allow for saving of the poi data points over time.
- Be fluid and responsive to the user.
- Provide an interface to construct geometric shapes, as well as modify and save those shapes.
- Provide a geometric framework that acts as a standard to work towards.
- Use poi that feel comfortable for the manipulator to use.

3.2 Prototype

The prototype I have developed consists of an object-motion capture system, a geometry system display and creation system, a recording system, an audio system, and an analysis system. The user holds a pair of podpoi - one in each hand - and manipulates the object with respect to a geometric pattern that consists of checkpoints, connecting lines, and boundaries shown on a screen. The system provides feedback to the user by means of visual indicators from a screen and by audio indicators.

The audio and visual feedback systems are modular, such that they run independently of each other, and thus, the user may disable one without effecting the other.

3.2.1 The object-motion capture system

This system uses both a hardware and software component. I will discuss each component separately.

The hardware consists of a Sony PlayStation 3 camera, a tripod, a 3d printed tripod adapter, a laptop, and a pair of podpoi.

The softare consists of a CL-Eye driver for windows, that is licensed to be used for academic purposes. Openframeworks has been used as the foundation to build the tracker on. In openframeworks, I make use of OpenCV, ofxXMLSettings, and a rewritten openframeworks library to connect to the CL-Eye driver.

3.2.2 The hardware

In the first prototype, the hardware I experimented with is as follows:

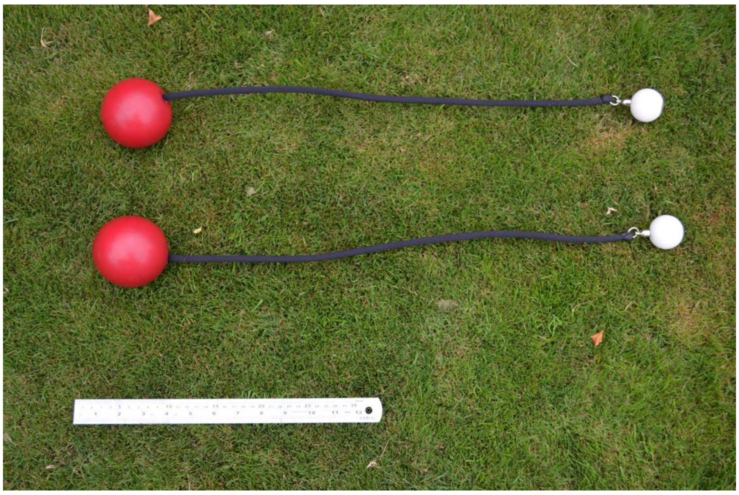


Figure 7: Practice Pendulum Poi

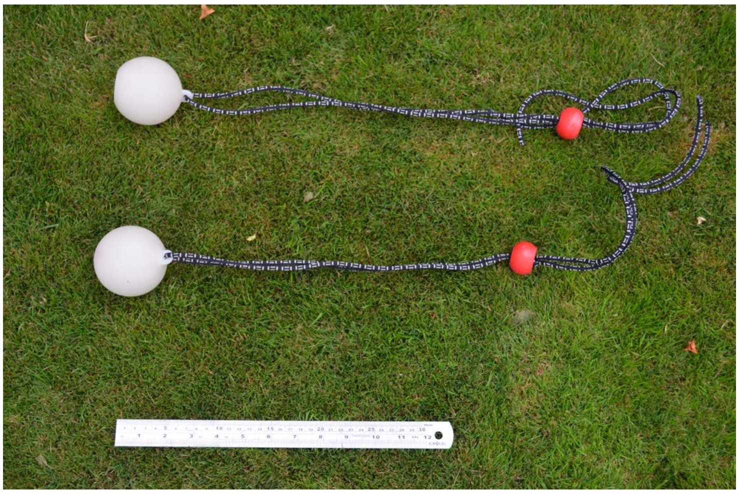


Figure 8: Glow Poi made from a round sphere

One attempt in the design involved making some infared glow poi 9, because I thought that infared tracking could be easily achieved with the wii or other suitable sensor.

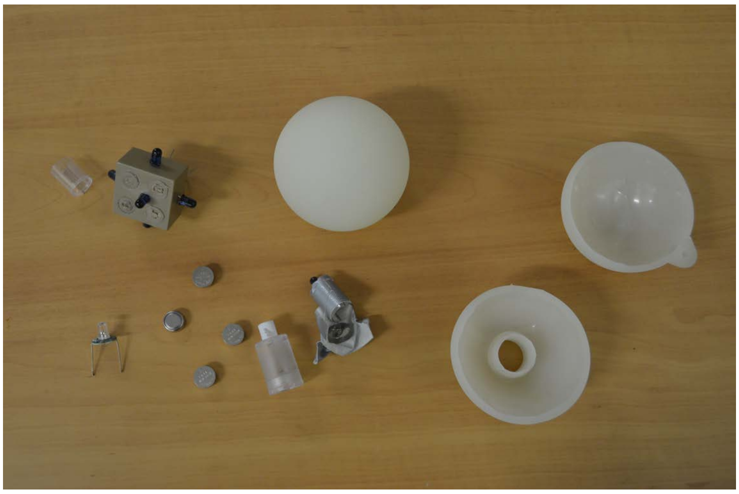


Figure 9: Infared Glow Poi

I found that designing a pair of poi in this way did not yield the expected results. The infared light that the poi emitted was not strong enough to come through the sphere. In further design on this part would have required the design of some entirely new poi. From here I also discovered that with the Nintendo Wiimote, pictured below, that its viewing angle was roughly 30 degrees. This is effectively tunnel vision and for the system to be able to track movement with up to 2 and a half metres of vertical and horizontal width, near possible. Some tests showed that I order to achieve a suitable horizontal recording distance, I had to be so far away from the stationary wiimote, that the wiimote could no longer detect the infared light.

The second prototype makes use of OpenFrameworks as the foundation, using the programming language C++. OpenFrameworks, just like Processing, does allow for rapid application development, but at the same time, it is still a fundamentally more difficult framework to use. The framework also lacks well supported documentation.

I have made use of the Sony PlayStation 3 camera due to the fact that it offers 125 frames per second operation. This camera can also be bought for under 100 New Zealand dollars new, or it can be bought for around 30 New Zealand dollars secondhand. It provides this frame-rate with a 320 by 240 pixel image. Through software, I can also control the camera's settings, such as its exposure time, gain and white-balance. The reason such a high frame rate camera is required is because poi can be manipulated through space at a very fast pace. The camera also offers 75 degrees field of view, which has proven to be sufficient when tracking movements of up to 3 metres.

The podpoi I am using are ideal objects for tracking. They're designed with performers and learners in mind. They're housed in a soft-silicone shell, which means if one hits oneself, then oneself isn't likely to hurt oneself. They contain 4 RGB LED's, and offer a mode where the user may select a continuous solid colour. They're also shaped like a teardrop, which makes them ideal for blob detection and tracking.

I make use of a tripod and 3d printed mount so that I can place the ps3 camera in an appropriate place. I also use a projector screen, a gaming projector, and two desktop speakers.

Figure 10: PlayStation 3 Camera

In the figure below you will find the poi that I used in the system. The poi are from a company called FlowToys. The poi are called PodPoi. They consist of an outer silicone shell, with a hard capsule in the center. The capsule has 4 RGB LED's in them, and offer many different colour modes. Most importantly, they offer a mode where I can set a solid colour from the colour spectrum. This allows for a good base that allows for solid and consistent tracking.

Figure 11: Glow Podpoi

3.2.3 The software

The first prototype I developed was in the Processing environment. In this environment, I was able to quickly and rapidly develop a prototype that used the concept of geometry that was savable, with checkpoints that the user would move the poi through.

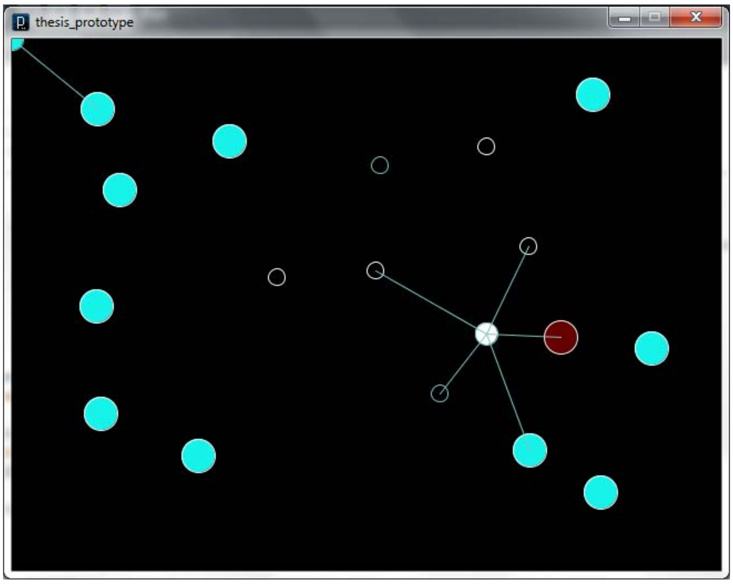


Figure 12: Processing Prototype

For the second prototype, I have developed a piece of software that uses OpenCV to calculate the poi position in 2 dimensional space. It is written in

C++ and it is using OpenFrameworks as a foundation. The software connects to a CL-Eye driver which is connected to the PS3 camera.

Now, it is important to describe how the software functions. The following paragraphs describe that functionality. In OpenFrameworks, there is a setup function, where variables are initialized, an update function, and a draw function. OpenFrameworks guarantees that update will be called before each draw function call. There are also functions to handle mouse click events, and keyboard events.

In the setup function, I initialise the PS3 camera wrapper, and instruct it to run at 125 frames per second. I load an XML settings file, using ofxXMLSettings. This settings file sets the last set gain and exposure values on the initialised PS3 camera. I also initialise some data structures to hold an RGB 320 by 240 image, an HSB 320 by 240 image, a hue 320 by 240 image, a saturation 320 by 240 image, a brightness 320 by 240 image, and a filtered 320 by 240 image.

I create an audio stream, that uses a buffer size of 512 and a sample rate of 44100. I also set the frame rate in OpenFrameworks to 125, as the update function will only be called as many times as there are draw calls. I set the vertical sync to false as well, because otherwise, the frame-rate would be artificially limited to the 60Hz of my monitor display. I also initialise my gui to control settings, set participant number, and select and save pattern numbers.

In the update function, the software checks whether there is a new frame in the buffer on the PS3 camera. If there is, the software updates the RGB image structure with a copy of the buffer. I next the RGB structure, and use OpenCV to convert the RGB image into HSB. I then extract each channel from the HSB image into a hue image, a saturation image, and a brightness image. If a filter value has been set, as well as min and max threshold values within that, then I compare each pixel on the brightness image to see whether it fits within the min and max threshold range, from the filter value starting point. If the brightness value is within that range, I set its corresponding position in the filtered image to white, and if not, then I set it to black. Once I have computed my filtered image, I run OpenCV's contour detection algorithm that is used for blob detection. The contour detection is condition by a min and max size that is also loaded from the XML settings file. Moreover, I also tell it the number of blobs that I am expecting. This contour detection gives me a structure, where I can loop through the blobs it has detected, and provides me with the centroid x and centroid y position of each blob.

At this point I consider my data stucture which contains the number of checkpoints currently displayed on the screen to the user, which also contains x and y coordinate data. I then see whether the any of the blobs are in close proximity, i.e., within 30 pixels of any checkpoint. If there is such a case, then I set that checkpoint's variable which tells me there is an object over it. For the distance calculation comparing the blob x and y position, with the checkpoint x y position, I am using the OpenFrameworks function ofDist, which takes 2 x coordinates and 2 y coordinates. if no blob is over a particular checkpoint, then I make sure to set that checkpoint's 'hasBlobOverIt' property to false. In the update function, I also update an array of previous positions, for each detected blob. I do this so I can display trails to the user, as this gives them a sense of where the poi has been in time.

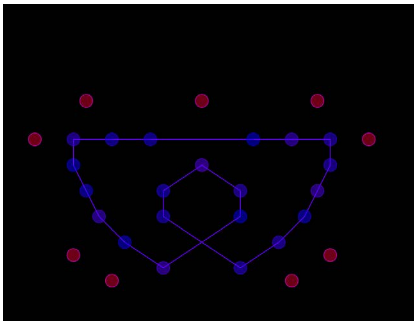
In the draw method, I scale the size of the 320 by 240 RGB image, so that it fits into a space of 960 by 720. This becomes the background of the screen that is displayed to the user. On top of this, I draw circles to represent checkpoints. If there is a connection between two circles, then I draw a line between them. If a circle has no connections, then it is classed as a boundary circle, such that the user ought to avoid passing the poi over or through it.

If a user has placed their poi over a checkpoint, and has not passed over a checkpoint previously, then the system will draw 2 bezier curves to all checkpoints connected to that checkpoint. This is supposed to indicate to the user that they can choose which direction to move in. However, once the user moves from that checkpoint to one of the indicated options, then the path vector is set. The user is then shown the next two checkpoints that they must move their object along. If a user misses a checkpoint, then an expanding circle is emitted from the circle they were supposed to pass through. When a user makes a mistake, the path vector is reset, so that the new checkpoint they passed through offers a choice in direction (if there more than one connection). Now, it is also possible for the system to switch the direction of the poi path. This is useful if the path is not cyclical, i.e., it has two definite end points. One the point reaches an end point check point, then the direction switches to go in the only direction it can, that is, back the way it came. If a user hits a boundary point, then in the draw method, I add an expanding circle, of random varying colour, at every frame, until the user moves the poi away from the boundary point.

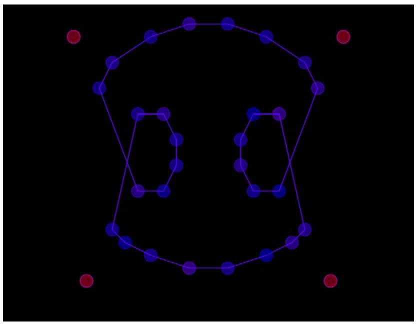
One of the software's features include the ability to load patterns, create patterns, edit patterns and save patterns. In the below figure, you will see the following four patterns that I have developed for the experiment.

I also developed 4 patterns, for participants to move the poi along. The participant could choose the direction they were to perform the pattern in, and the participant could choose which hand to use in the experiment. The first pattern 24(a) involves performing a pendulum-like pattern, with a small circle at the lowest point. Boundary markers were placed in regions where the participant would likely make mistakes.

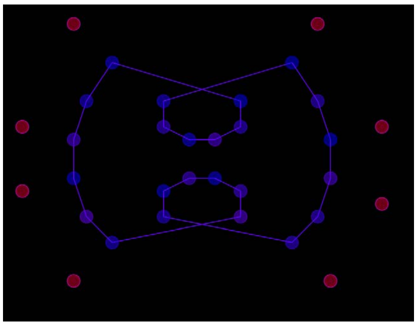
The second pattern 24(a) involves performing a *two-petal in-spin horizontal flower* pattern. The participants would ideally pause at the horizontal regions in order for a smaller circle to be made as part of the larger full-arm extended circle. Boundary markers are indicated as the redish circles and were placed in regions where the participant would likely make mistakes.



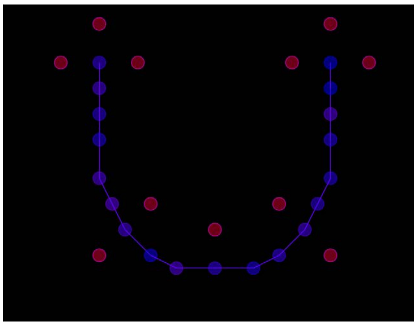
(a) Pattern 1



(b) Pattern 2



(c) Pattern 3



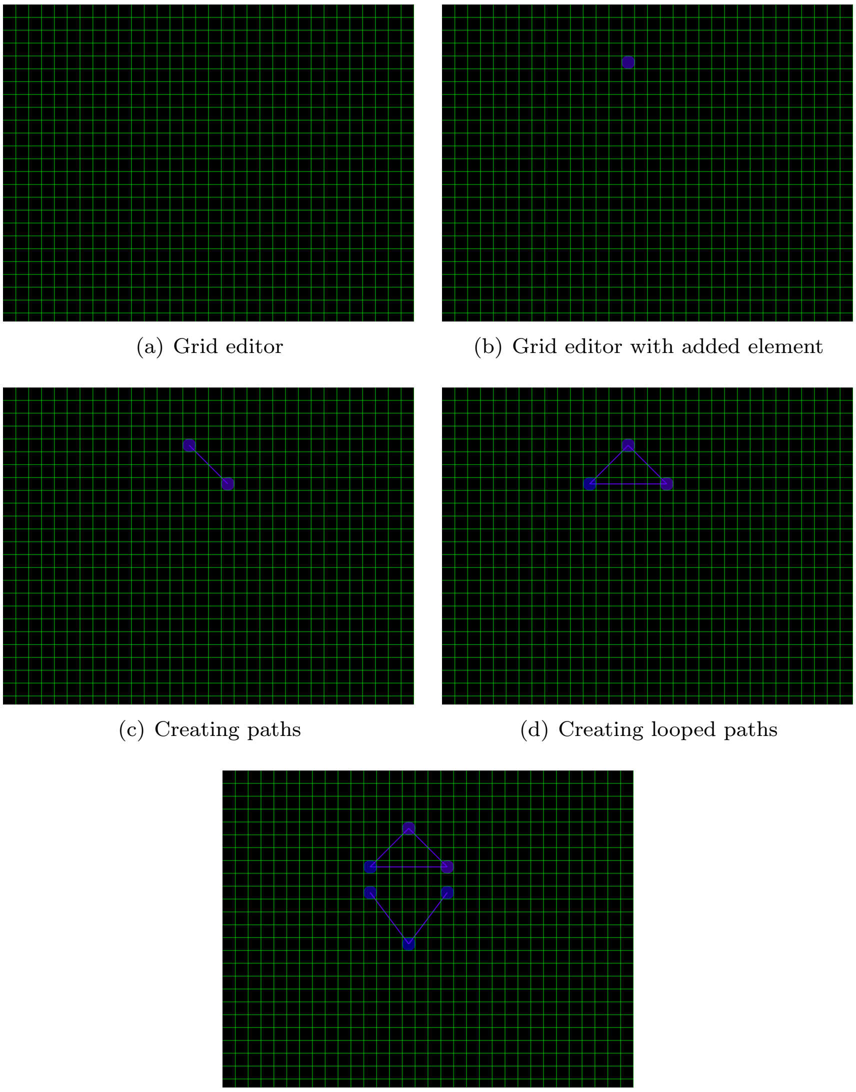
(d) Pattern 4

Figure 13: Created patterns used for evaluation and testing (a), (b), (c) and (d)

The third pattern 24(c) involves performing a *two-petal in-spin vertical flower* pattern. The participants would ideally pause at the vertical regions in order for a smaller circle to be made as part of the larger full-arm extended circle. Boundary markers are indicated as the redish circles and were placed in regions where the participant would likely make mistakes.

The fourth pattern 24(d) involves performing a stall and reverse pattern. The participants would ideally swing the poi to the top most region at either side, and then pull the poi back through the path that it travelled to reach that top-most point in the first place. The participant would then swing the poi to the other side, stall it, then pull the poi back through the path that the poi travelled through to get there in the first place. Boundary markers are indicated as the redish circles and were placed in regions where the participant would likely make mistakes.

The following figure 3.2.3 shows the grid editor that I have developed in the second prototype. This editor allows one to use the mouse to quickly and easily place checkpoints. All one needs to do is right click the mouse on a cell in the grid, for a checkpoint to be created in that position. If a checkpoint already exists in that position, then the checkpoint is removed. If the user presses a keyboard shortcut, in this case 'G', the system will draw a grid overtop of the positions of the checkpoints. Each cell is square in size. When a user places a checkpoint, the checkpoint is generated in the centre of a cell. This simplification on the resolution of checkpoint placement was chosen so that a user could make checkpoint patterns easily symmetrical. When the user presses the right mouse button with the mouse cursor over a cell, a checkpoint is created. If a checkpoint already exists in that space, then the checkpoint is removed. If the user presses the left mouse button down, and holds the button down, while over a checkpoint, then the user may reposition the checkpoint, by moving the mouse over different cells. The user releases the mouse button when the user is satisfied with the choice of placement.



(a) Grid editor (b) Grid editor with added element (c) Creating paths (d) Creating looped paths (e) Two types of circuits

Figure 14: Pattern creation system and editor. The grid editor is shown in (a), adding elements is demonstrated in (b), creating a connecting pattern in (c), creating a looped pattern in(d), and combining them in (e)

In the figures 14(b) and 14(c), I show the concept of developing paths with the checkpoints. Once two or more checkpoints are created, then if one holds down the 'z' key, and left clicks the mouse on one checkpoint and then on the next checkpoint, a line will be drawn between them. Once a line is connected between them they are immediately usable.

Now, when creating looped paths, see Figure 14(d), all one needs to do is to keep creating the lines in an order, as described above, but this time, a final connection is made between the last checkpoint and the beginning checkpoint. When the user moves the tracked poi to one of the checkpoints on the path, the user will be presented with a thickened line, made from two bezier curves on connecting to the previous checkpoint and the next checkpoint. This allows the user to pick which direction to move their object in. Once the user moves the poi to one of the other checkpoints, a direction vector is set, and then the next checkpoint that the user ought to move the poi to is defined, as well as the one after that.

Multiple kinds of loops can also exist on the same pattern, see Figure 14(e), and this allows for a large number of simultaneous patterns to run on the screen at the same time. This type of technique could be very useful if a certain pattern requires that distinct patterns to be performed with each hand at the same time. See the following picture as an example of this.

The pattern loader, see Figure 15 allows one to select from 4 pre-created patterns, as well as create new patterns to save on those placement slots. Moreover, this area also allows the user to change the behaviour of the circle elements on the screen, i.e., from checkpoint to boundary marker. This area also allows one to select the tone that is generated when a checkpoint is struck.

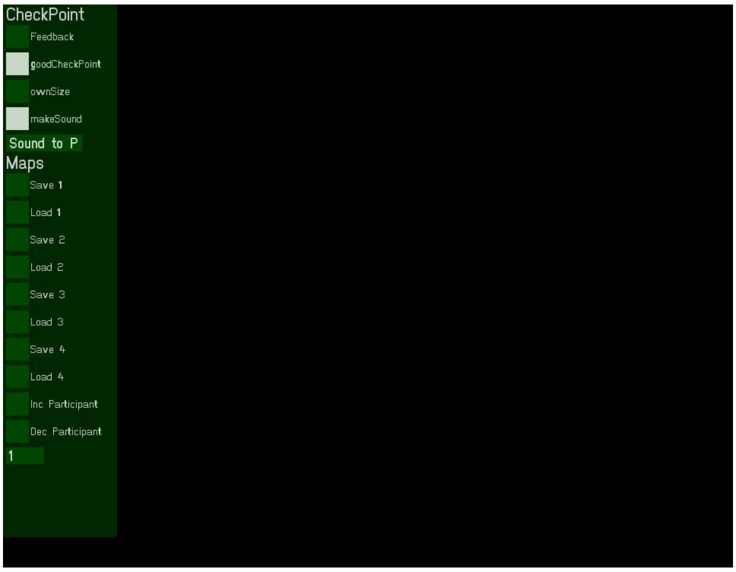


Figure 15: Loading patterns and making adjustments

3.2.4 Lessons learned

While capture system runs at 125 frames per second on moderate computer hardware, it is by no means truly optimised. There were also certain discoveries made, such as that OpenFrameworks ties its Draw and Update functions together, so the update function is only ever called as often as the draw function. A consequence of this is that in order for the system to process more than 60 frames per second, then the system cannot have vertical sync enabled on a traditional screen. This results in some image tearing. In the future, to solve this, multiple threads ought to be created to solve this issue.

3.2.5 Data Recording

The system records poi movement data, and can replay this data after it has been recorded. It also records checkpoint interaction data, such as when a checkpoint is hit, whether that checkpoint was part of a sequence, whether that checkpoint ought to have been hit or not, and the time each checkpoint was hit. The poi movement data records the poi's x and y coordinate position for each frame. Scores can then be evaluated over time, and graphed such that one can visually see whether they have improved in their average over time or not. It is also possible to count errors over time. It is conceivable that the error frequency could go down as the person becomes more adapt at performing the pattern in front of the system. Now, I save that information into some data structures, and then save them to XML using the ofxXMLSettings library. The system saves this data to XML format, and thus, it allows the information to be loaded into any editor or software that supports XML. This information is saved using the ofxXMLSettings library.

4 Field Testing

The evaluation of the training system went through two distinct phases. The first phase of user evaluation consisted of field testing at a festival. The second phase of user testing consisted of an experiment. For the field testing evaluation, the goal was to determine whether it was feasible to use the training system in a festival environment: to gauge user perception of the training system, to test other kinds of objects (such as juggling clubs, double staffs, dragon staff, astrojacks) in both glow and fire varieties, and to find suggestions for improvement. I arranged to take the training system to Luminate Festival 2013, where it would be setup and run as an installation for 3 of the 8 day festival. The system was setup at night, due to the need for a dark lighting environment for both the tracking algorithms and for the projector. I took the following equipment to the festival:

- A pair of podpoi
- A podpoi USB battery charger

- A short draw projector
- A pull up standing projector screen
- A laptop with the software and drivers installed
- Extension cables for power, and a spare powerboard
- A tripod with mount for the PS3 camera
- A PS3 camera
- Black sheeting to control the lightning behind the user of the system
- Plastic containers to securely hold all of the components

The first challenge once I arrived at the festival was to organise power for my system. This took considerably longer than I had hoped, due to the fact the there was no cell-phone reception available on-site, and the fact that it was difficult to ascertain which individual I should speak to about organising power. After the third day of the festival, I managed to track down the right person, arrange power for the circus tent. That night I setup the training system inside the tent. The lighting conditions at night inside the tent proved to be ideal, and no adjustment of the tracking threshold was required to track the podpoi. I tried projecting onto the clear plastic tent wall, which had been covered in a layer of condensation due to the temperature differential between the inside of the tent and the outside of the festival grounds. This allowed for the system's display to be seen by people playing with the system, and for people outside the tent to see a visual display on the tent's wall. However, due to the fact that a portion of the light was travelling through the screen, it meant that the screen the user saw was quite faded and hard to see. After playing with the system in this manner for two hours, I made use of the pull-up projector screen. This did mean that only the individuals in the tent could see the user playing with the system, but it did mean that it was a lot easier to see the screen.

The focus of this test was to gauge whether the system could run in a festival environment.

On the second night, the plan was to setup the training system outside so that a greater variety of people could experience the system and provide feedback. However, about 15 minutes after the system was setup outside, it began to rain. I quickly the setup inside the tent, and changed the purpose of the tent to test different trailing effects, as well as to construct some new patterns for people to explore. On the third night, it was no longer raining, so I had the opportunity to setup the system outside the tent. This proved to be an ideal time, as the festival was in its winding down phase. I noticed many people over the course of 5 hours use the system, and many different passers by stop and look at the system.

It also proved to be an opportunity to test how the system worked with other types of objects. Each test consisted of selecting a particular kind of toy to stand in front of the system at a time, and to explore typical movements performed with those objects.

We tried LED glow juggling clubs and performed both club juggling and club swinging with them. It proved difficult to track as single entities. I think this was because of the form of glow juggling clubs. The issues encountered with juggling clubs proved to be to-do with the fact that the entire juggling club was illuminated at a single time, and the fact that the hand holding the club necessarily conceals some of the light. This meant the tracking system saw two distinct points of light per club: 1 point from the handle end, and 1 point from the club end. I found that there was a way to get them tracking properly, and this involved concealing from the camera the handle end of the club. It may be possible in the future to get this tracking if one could model the characteristics of clubs, combined with skeletal tracking from the Microsoft Kinect. If one could find out where the hand position is, then it would be possible to take that position, as well as the club head position, and to then draw a line to guess where the club handle light ought to be. If it finds this light, then the system should ignore the light. Modelling the shape of the club could be another possibility. Fire juggling clubs proved to be a lot easier to track, because only the head of each club is illuminated. See the below figure for an indication of this.

Figure 16: Fire Clubs

Fire clubs, see 16 are used to in the practice of juggling and for club swinging. Club swinging involves in most cases the holding and manipulation of the clubs without the clubs leaving the hands.

Another type of object we tried was a staff.

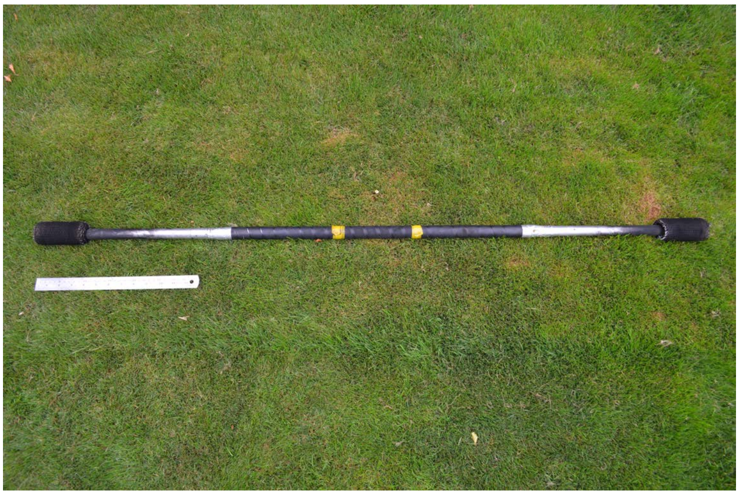


Figure 17: Contact Fire Staff

While a staff could be tracked by the training system just fine, since there were only two points of light (one at each end) to track, it is possible that front facing tracking isn't practically useful for staff spinning. For example, with a staff, many of the moves involve spinning the staff behind the manipulator, and as such, the camera of the training system is unable to track the staff's movement during that time. It was unlikely that both points of the staff would be simultaneously obscured from the camera. There are also many moves that do not require geometry for staff. For example, contact staff involves keeping a part of the manipulator's body underneath the centre point of balance of the staff. This is naturally a challenge for the manipulator, where the eyes are generally focused on the balance point. Moreover, contact staff does not seem to rely on movements with respect to geometric frameworks. At least, not to the extent which poi relies upon geometric frameworks. However, it may be possible to predict the movement of the staff using just one camera, and a model for how a staff typically moves, as well as knowing the distance between each end point of the staff. For this experimentation we tried a fire staff, which we found could be tracked really easily.

Another type object that I tested was double staff. Double staff comprises generally of two shorter staffs when compared to the length of contact staff or staff. While the length of double staff varies, each staff is the same length as the other. The type we used were measured to be twice the distance from the performers hand to elbow. The manipulator used the double staffs standing towards the camera, and performed many different kinds of manipulations that are typically performed in the wall plane (i.e., they are in front of the performer). Double staff effectively has 4 points of trackable light. This required that the training system be able to track that many points of light. Earlier in the day, I had programmed the ability to track up to 4 points of light. However, it should be noted that, upon seeing the performer use double staff, I noticed that the code I had written contained some bugs. The bug concerned the trailing effect for each point of detected light, but not whether the system detected the light source or not. The performer made a point of telling me that he thought the training system would be extremely useful for double staff, perhaps even more so than it would be for poi. Double staff is, by its current nature, very much rooted in geometric patterns and structures, and as such, my training system is naturally suited to these types of movements. The double staffs were fire and not glow. It would be very interesting to test glow based double staffs at a later date.

At the festival there was also an LED dragonstaff, which proved to be very interesting to try to track. The performer tried some typical manipulations with the staff and I noticed that the system struggled to keep up with the very fast rotation of the dragonstaff and the low light nature of the glow ends. The LED dragon staff used 4 glow flowlights at each end. A flowlight has 3 LED's, with one situated at one end, while the other two situated at the opposite. This meant that the tracking system would often see the each end of the dragon staff having 8 points of light. The system was not currently designed to handle that many points of light, which may have been a factor in why it handled it poorly. We also tested some fire astrojacks, which consisted of 4 siding tubes with kevlar on along a chain. It was found that while the training system could track the astrojacks, due to the highly dynamic and unpredictable nature of astrojack movement, that the training system was not found to be that useful in that scenario. Further to this, astrojacks seem to require one's field of vision placed firmly on the moving astrojacks, and not on a screen in front of them.

There was also the opportunity to use fire poi, as opposed to glow poi 20.

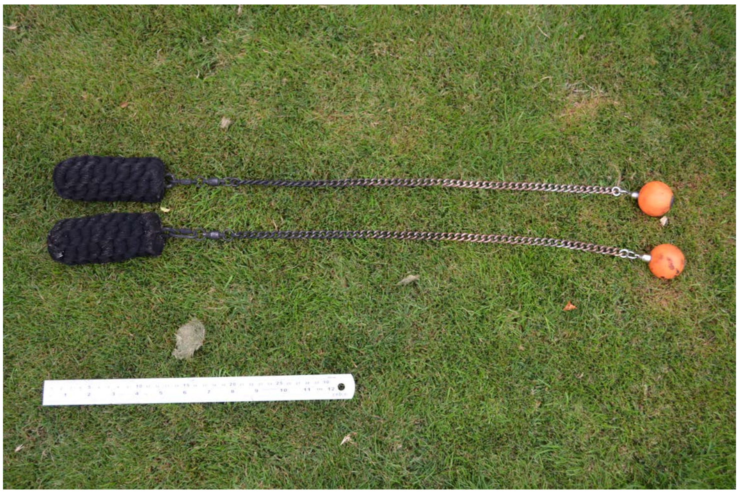


Figure 18: Fire Poi

It was found to be extremely easy to track fire poi, because they emitted even more light than the glow poi I had been using. I tried many of the same manipulations that I had been doing when testing the training system at the HITLab NZ with glow poi. After this test, I was able to confirm that fire poi work well on the training system. One issue I noticed when doing these tests with different fire props, was that occasionally, there were other performers in the distance also performing with fire, and the light from that fire was still enough for the training system to attempt to track the objects. Because of the limit the system currently has on the number of trackable objects, it meant that at times, there were more trackable blobs within the camera's view than was intended.

4.1 Reception

The reception of the training system was very favourable. At least 15 different object manipulators tested the system, and all praised it for its real-time feedback ability. It was also seen by many of the festival goers, some of which I managed to have brief but valuable conversations with. I found that through the conversations, that people could immediately tell that the system was responding to the movements of the manipulator using the system. Moreover, many mentioned that it was great to be able to see the patterns by way of the trail effect that the manipulators were making. Some of the people watching were unsure of whether they could have a go, and in those cases I had to explain that everyone was welcome to play with it. In the future, I think a clear sign saying everyone is welcome to use the system would be a good idea. One of the crowd who was a beginner at poi had a go, and performed 3 different tricks they knew. Afterwards the beginner came up to me and provided feedback. She mentioned that she did not find the patterns she knew were very aesthetically rewarding when represented by the training system. I think it may be very important to try to create aesthetically pleasing representations for beginner through to advanced movements, rather than the most aesthetically pleasing to just be relegated to the advanced movements. It was also noticed, however, that in the system's current state, that it didn't really have any clear objectives, other than, 'hitting the circles on the screen'. On the third day, when the system was outside, there was even a queue of people waiting for a turn on the system. It was noticed that object manipulators with more experience generally could construct more interesting visuals than beginners. This is understandable, of course, but if the goal is to create reward mechanisms, then it would be useful to think how to reward beginners to the same degree that highly experienced manipulators are rewarded.

4.2 Conclusions from the festival evaluation

During the festival, it was possible to find answers to a number of different questions. It was found that it was feasible to setup the training system both inside and outside in the environment. Moreover, projector screens are not necessarily required (for example, it was possible to project onto the clear tent screen). A number of different performance props were tested in both glow and fire varieties. For example, it was found that double fire staff worked extremely well with the geometric foundations of the training system. The system could successful track fire staff, fire clubs, fire poi, and double fire staff. The system also successfully tracked glow poi 20. The system had trouble with glow dragonstaff and glow clubs (the clubs needed to have the handle end covered by the hand fully in order to not track those parts). The response from the installation at the festival was extremely positive, and many of the festival goers said they really enjoyed playing with the system or watching the system being used. With the way the system is currently designed, that is, a single camera perspective and the focus on geometry, it was found that double staff and poi suited themselves to be used with the system the most out of the other objects tested. Difficulties experience with the festival concerned finding power sources, and the ability to adequately control lightning of the environment behind the object manipulator. It was also noticed that in the festival environment, while it was possible to write code and make adjustments, there did not seem to be adequate time to test changes to the code to make sure every new addition worked as expected.

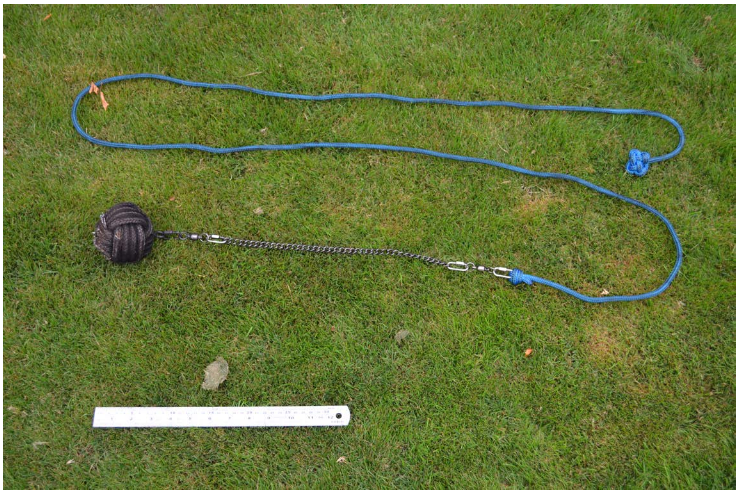


Figure 19: Fire Ropedart

Figure 20: Glow PodPoi

5 Evaluation

5.1 Introduction

In order to evaluate the training effectiveness of the object manipulation system I constructed, it is useful to compare it to an existing and common form of object manipulation training. The existing form that I've chosen is mirror training. Mirror training involves the object manipulator to be in front of a mirror of sufficiently large size, such that the manipulator can see the manipulator's entire body and the entirely of the prop around the manipulator's body. It is also a common practice for object manipulators. When the manipulator is in front of the mirror, the manipulator will move the prop in intentional ways, and at times, the manipulator will focus on specific patterns or paths that the object can move through. If the manipulator is focused on moving through a specific path, the manipulator may also draw that path on the mirror, using, for example, an erasable marker. The manipulator can then use the drawn path as the objective path to move the prop along. Now, I have made a representation of the mirror system within the object manipulation training system. I emulate what I will henceforth call mirror feedback, by disabling visual and audio signs of path interaction within the system. However, the system will still register every position of the poi, it will just not display the visual and audio feedback to the manipulator using the system. Thus, I will compare mirror training with feedback training. I wish to see whether participants do better with the feedback system when compared with mirror feedback. The way I measure this is through the data recording facility of the object manipulation system. One of the difficulties in achieving this task will be the variability of skill in the participants, and the requirement of having some (although very little) previous poi experience. Furthermore, the possibility of participants becoming fatigued throughout the experiment period is a real concern.

In order to investigate my research question, that is, how does the feedback training system compare to mirror training in terms of its training effectiveness, I conducted a within participant experiment. Each participant was exposed to 2 conditions: training-feedback and mirror-feedback. Each participant had 4 pattern training tasks to perform. Each pattern was selected to be of similar difficulty. However, the movements were not classed as 'beginner' patterns, and as such, it was required that participants had at least some prior experience. I randomised the order in which the patterns are given to each participant, and I counterbalanced whether the first two patterns are feedback or whether the last two patterns are feedback. One of the difficulties in achieving this task was the variability of skill in the participants, and the requirement of having some (although very little) previous poi experience. Furthermore, the possibility of participants becoming fatigued throughout the experiment period is a real concern. Hopefully, by randomising the pattern order, and by counterbalancing whether the first two or last two patterns are feedback will reduce these possible confounding factors.

For each pattern the participants performed, the training system recorded every poi data point over a set period of time. In this case, each pattern was recorded for 3 minutes of total time, but the first 10 seconds was omitted due to calibration time, and the last 20 seconds was omitted due to the researcher coming back into the experiment room to turn off the recording. Now, the system also records all of the interactions the poi have with checkpoints or boundaries on the screen. For each pattern, the participants are shown, by the research assistant, how to correctly perform the pattern before the participants try. The research assistant also shows the participants how to hold the poi. For the research, participants were only required to hold one poi at a time. This is due to the fact that, under normal training conditions, when participants are learning a pattern for the first time, it is in their best interest to learn with one poi first, before moving to a second poi.

Now, I analyse the data in two ways. The first way compares the scores participants receive from hitting consecutive checkpoints over time. With the recorded data, I average the scores a participant receives into 10 second intervals. Because there is 150 seconds in two and a half minutes, there are 15 intervals per pattern. I then compare scores for each interval between participants, using a generalised linear model, followed by a regression analysis.

The second way analyse the data is as follows. I calculate the relative distance the poi is away from the objective path the poi ought to follow at every data point, then average those distances into 10 second intervals. Just as in the analysis, these are also over 15 intervals. I then compare the average distance away for each interval between participants, using a generalised linear model, followed by regression analysis.

5.2 Participants

In the experiment, 21 participants were selected, but only the data from 20 was used. This is due to a computer malfunction. A pre-requisite was that the participants have at least 15 minutes of prior poi experience, and the knowledge about poi planes. This ensured that the participants would understand the objective of each task correctly. In order to select these participants, notices were posted on popular facebook groups for object manipulation and performance art. Furthermore, given that I am a performance artist, I had the available community connections to call on other performance artists and hobbiest object manipulators in the community to be a part of the study. This is a possible source of bias, because the participants could have wanted to please me in the study by saying nice things but ignoring possible problems. There was no criteria for age or gender, other than them being legally able to sign a consent form.

In the experimental process, I first applied for a low-risk ethics approval application from the University of Canterbury Human Ethics Committee.

5.3 Materials

In the experiment, made use of a room measuring 3.5 metres by 6 metres and the following equipment:

- A set of podpoi
- A PlayStation 3 camera
- A Tripod
- A 3D printed PlayStation 3 tripod mount
- A pull-up self standing projector screen
- An Optoma GT750E short-draw projector
- A tablet computer
- A laptop computer
- Three tables
- Two chairs
- Black curtains
- Black sheets
- Two desktop speakers

The black curtains were hung up behind the participant. This allowed for the camera to track the poi without other objects in the environment obscuring or reflecting too much light. The black sheets were placed above the black curtains as well as to the side of the black curtains to hide more reflective surfaces.

Figure 21: Backdrop used in the experiment.

I placed the 3D printed PS3 mount on the tripod, and the PlayStation 3 camera slotted into the mount. I placed the pull-up self standing projector screen against the wall opposite the black curtains. The tripod was placed 1 metre away from the projector screen. I put a table 1.5 metres away from the projector screen, and on this table I placed the projector.

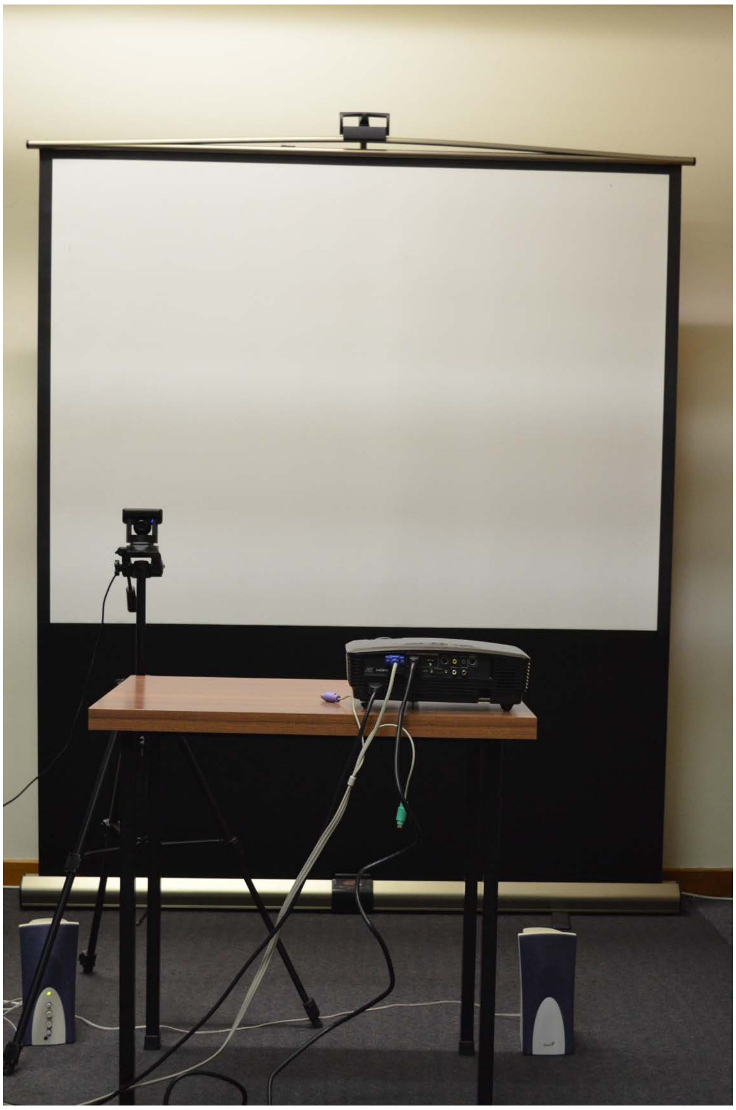


Figure 22: PS3 camera, tripod, PS3 tripod mount, and table in relation to projector screen for experiment.

When facing the projector screen, I placed another table to the left, which the laptop was put on. The projector was connected to the laptop via the RGB connector, and the speakers were connected to the laptop via the 3.5mm stereo audio jack.

Along that same left wall, I put a table with the information sheet, consent form, and a tablet with an online survey using the qualtrics survey system.

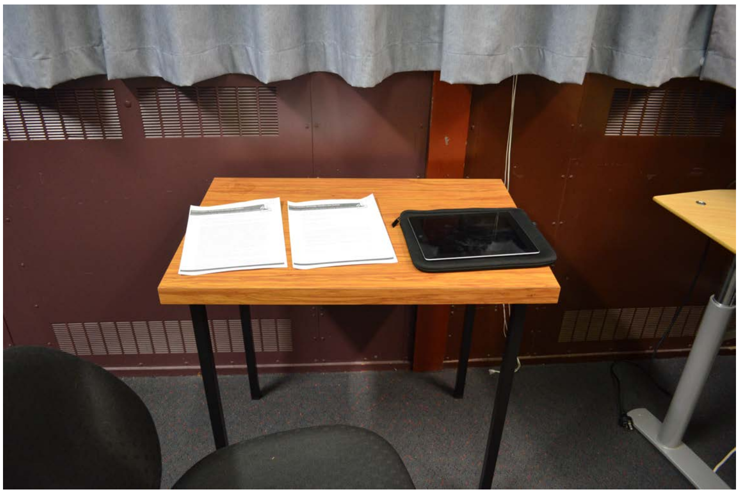


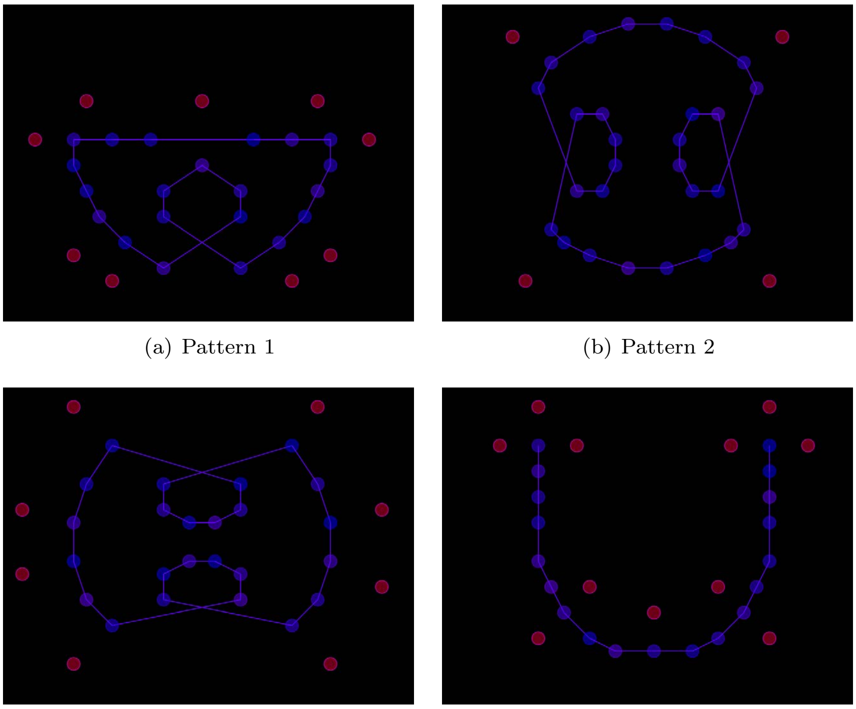
Figure 23: Data entry chair and table for the experiment.

Now, in order to record the data during the experiment, I developed a data recording module for the object manipulation training system. This module records the x, y position and time position information of the poi on the screen for every frame that the object detection algorithm detects an object. The system is designed to run at between 100-125 frames per second, and thus the maximum possible data points using a single poi is 125 positions per second. Not only do I record every position of the poi, I also record the interactions the poi have with the checkpoints and boundaries. For each interaction, I record the time that the poi passed into the checkpoint's or boundry's region, the x and y position of the poi, and whether it was expected or not. In order for a checkpoint to be expected, the participant ought to be moving along a trajectory, and along the trajectory, there are checkpoints for the participant to pass through with the poi. If the participant misses a checkpoint, then the next checkpoint of boundary the participant hits, will be counted as a mistake. Now, for each pattern that is recorded, there is a total of 3 minutes of recorded data for each of the two above described forms of data measurements.

I also developed 4 patterns, for participants to move the poi along. The participant could choose the direction they were to perform the pattern in, and the participant could choose which hand to use in the experiment. The first pattern involves performing a pendulum like pattern, with a small circle at the lowest point. Boundary markers were placed in regions where the participant would likely make mistakes.

The second pattern involves performing a two-petal in-spin horizontal flower pattern. The participants would ideally pause at the horizontal regions in order for a smaller circle to be made as part of the larger full-arm extended circle.

Boundary markers are indicated as the redish circles and were placed in regions where the participant would likely make mistakes.



(a) Pattern 1 (b) Pattern 2 (c) Pattern 3 (d) Pattern 4

Figure 24: Created patterns used for evaluation and testing (a), (b), (c) and (d)

The third pattern involves performing a two-petal in-spin vertical flower pattern. The participants would ideally pause at the vertical regions in order for a smaller circle to be made as part of the larger full-arm extended circle. Boundary markers are indicated as the redish circles and were placed in regions where the participant would likely make mistakes.

The fourth pattern involves performing a stall and reverse pattern. The participants would ideally swing the poi to the top most region at either side, and then pull the poi back through the path that it travelled to reach that top-most point in the first place. The participant would then swing the poi to the other side, stall it, then pull the poi back through the path that the poi travelled through to get there in the first place. Boundary markers are indicated as the redish circles and were placed in regions where the participant would likely make mistakes.

5.4 Design

The experiment used a within-subject design, with score and distance away from objective path as the dependent variables, with feedback as the independent variable. There were also 4 distinct patterns that the participants were to all attempt. The order in which participants received each pattern was randomised.

5.5 Measurements

The experiment measured the horizontal and vertical axis of the poi in space. It did this by using a PS3 camera to detect and isolate only the poi in the environment. The system took this coordinate and displayed it on top of a screen, that also had a pattern drawn on it. The system then used the location of the poi on the screen, relative to the drawn pattern, as the basis for all the calculations. These calculations included location time, whether the participant had just hit a checkpoint, which checkpoint that was, whether it was an expected checkpoint (i.e., the system expected the participant to hit that checkpoint and not another checkpoint), what the next expected checkpoint was, and whether it was an error. As well as the checkpoint measurement system, there was also a least distance away from the objective path at all recorded poi data points.

The experiment also measured, by way of a survey, the engagement participants felt towards the two conditions, that is, av-feedback and mirror-feedback. The survey was given twice, once after the first condition was completed, and once after the second condition was completed. The same survey included in the engagement questionnaire information that allowed one to measure flow state. The participants also filled out some descriptive questions at the end of the engagement survey.

Finally, the experimenter took note of any difficulties participants expressed to the experimenter, as well as any potential issues that the experimenter noticed.

Now, insofar as the distance can be interpreted, the values are in pixels. The camera has a resolution of 320 pixels by 240 pixels. The participants stood 3 metres away from the camera, and had an poi reach of 3.5 metres. This meant that for every pixel of movement 10.9mm of space was covered. The system then effectively had a resolution of 1cm at this distance.

5.6 Procedure

The experiment took between 30 minutes to 45 minutes per participant. After the participant arrives at the HITLab NZ, I would greet the participant and show them into the experiment room. The research assistant would ask the participant to take a seat and read through the information and consent form. Before signing, the research assistant would check to see if the participant had any questions about the experiment. If yes, then the research assistant would attempt to answer those, and if no, then the research assistant would wait for the the participant sign the consent form. After the participant signed the consent form, the researcher would hand the tablet to the participant and ask the participant to fill out a short survey with non-identifiable information, such as age, gender, and questions about previous poi or object manipulation experience. Once the tablet is handed back to the research assistant, the research assistant would demonstrate the feedback system to the participant. See the below figure for an example of this:

Figure 25: A researcher interacting with the system and demonstrating the movements for participants.

Once this is completed, the researcher would ask the participant to spend 2 minutes to warm up and familiarise oneself with the podpoi. The researcher would then explain to the participant that there will be four patterns to learn. For each pattern, the participant would be given 3 minutes to aim for the best score. Two of the four patterns would have no computer aided feedback, and would only make use of mirror-like feedback, while the other two patterns would have computer aided visual and audio feedback. After the participant performs each pattern, the participant would be given 1 minute to rest. After the first two patterns, the participant is given a questionnaire to fill in, referred to as a game engagement questionnaire (Jeanne H. Brockmyer, 2009). After the participant fills this information in, and hands the tablet back to the research assistant, then the research assistant begins the next of the last two patterns. Below is an example of how mirror-feedback condition appears to the user, and how visual-audio feedback appears to the user, see figures 26 and 27.

Figure 26: Mirror feedback for experiment.

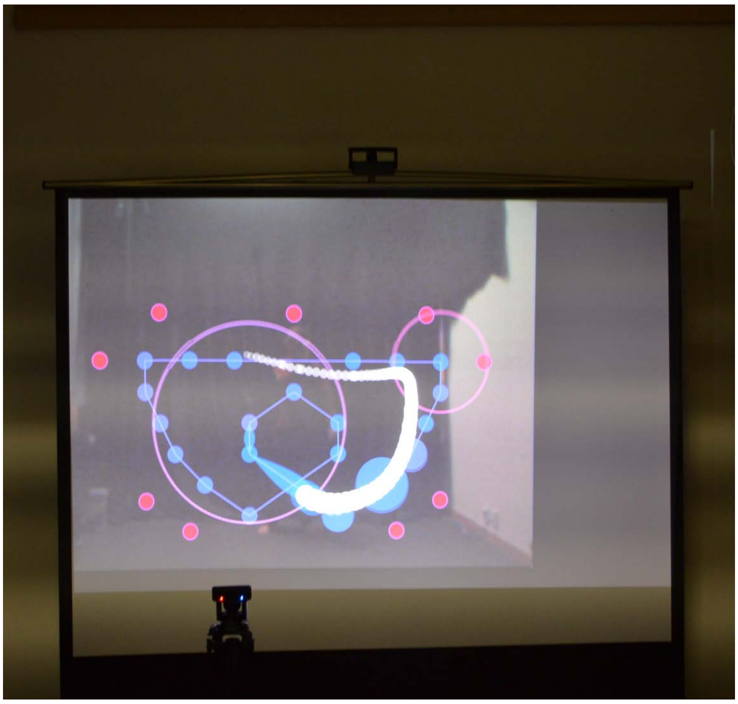


Figure 27: Visual and Audio feedback for the experiment.

Finally, there would be an identical game-engagement questionnaire that asked this time for participants to only answer the questions for the last two patterns. Thus there is a game-engagement questionnaire for both feedback and non-feedback conditions.

5.7 Results

In this section I provide the summarised results from the within user study I did. Moreover, I explain how the data was analysed and captured from the feedback system. The section is broken into 3 parts. The first part deals with the results from the data measured by the application. The second part deals with the results of the Game Engagement Questionnaire, and the final section deals with the descriptive writing given by the participants, and the observations made by the experimenter. However, it is important to note that in this section I will be describing the process I went through in analysing the data. This means that it is narrative based, and is designed to indicate the reasoning process I used to analyse the data.

Now, for the data measured by the application, I have been interested in two measures. The first measure calculates the scores each participant received over time. Scores are received by having the poi pass through successive checkpoints on the graphical display in front of them. As soon as a participant makes an error, the score resets back to zero. Using the same poi data set, that is, the time indexed horizontal and vertical coordinates of the poi relative to the geometry, I have also calculated the minimal distance away from the objective path that the poi ought to be moving along. The times that each frame is captured varies between participants, due to variances in CPU load. Therefore, I have averaged the scores over time intervals. The reason for this is that I can then compare one time interval to another time interval. The poi data points are accurate to the milisecond level, and as such, the recorded time would rarely, if ever, coincide. I first compared the average means between the AV-Feedback and the Mirror-Feedback conditions using a paired-sample T-test. Due to not finding any favourable results, and due to the fact that I thought it was possible that the averaging concealed important information, I then compared the average score over each 10 second period of the total measurable recorded time of 150 seconds, and considered this with respect to AV-Feedback and Mirror-Feedback. I used a repeated measures ANOVA for this. I did not find significant results from this method, and so decided to try a more advanced type of test: a mixed generalised linear model. The mixed linear model did yield significant results, however, after running a Q-Q plot on the residuals, it was determined that the model does not adequately predict or equal the data. Finally, I compared the average distances between AV-Feedback and Mirror-Feedback.

After that I had exhausted the main possibilities from the poi data, I moved onto analyse the 3 point likert scale game engagement questionnaire. There were 19 questions that participants had to fill out twice, once after the first condition, and once after the second condition. This allowed me to compare av-feedback to mirror-feedback.

Once the survey results were analysed, began to investigate the observational and descriptive results from that I noticed myself, as well as the ones that the participants wrote down.

One participant has been omitted due to errors in the recording application at the time of the experiment.

For the first analysis, the scores per participant are collected over the total meaursable time (150 seconds) and then the mean score is determined. A paired sample t-test is then run on that data to compare AV-Feedback and Mirror-Feedback. We found that there is not a significance difference between av-feedback and mirror-feedback conditions.

It is possible that information may have been hidden in the averaging of the data. To consider this aspect, I also broke the total 150 seconds of recorded data per pattern into 15, 10 second blocks. In each block is the average score for that time period. A repeated measures anova was run on that data, and it was found that the data does not show a significant difference in score over time or with feedback.

The second measure considers the distance away from the objective path the poi ought to be on for every sample taken. The first 30 seconds of time, as well as the last 30 seconds of time was averaged, and it was found that there is not a significant relationship between av-feedback and mirror-feedback conditions.

5.7.1 Paired Sample T-Test on Total Mean Scores

The first type of comparison test I did was a basic paired sample t-test. I aggregated the recorded data from each condition for each participant into a total mean score over the recorded time of 150 seconds. At this stage I was interested in whether there was a noticable difference between av-feedback and mirror-feedback. It was found that there is not a significant relationship between av-feedback and mirror-feedback, such that $T(19) = -1.158$, $p = 0.261$, and therefore using this type of test did not yield significance. It is also important to note that there is a large amount of variability in the data, which could indicate a large difference in the participant skill level. The following table 1, indicates this variability if one takes note of the standard deviation amount.

Now, it was possible that due to the data aggregation, that important data was being hidden from the tests. I decided to break the 150 second recorded time into discrete intervals. Each interval is over a period of 10 seconds. In that time, I used a computer program which I wrote that would count and average

Table 1: Total Mean Comparison of Scores

Paired Samples Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
Mirror Feedback	6.94	20	2.91	0.65
AV Feedback	7.69	20	3.45	0.77

the score over the number of scores for each period. I therefore chose a repeated measures ANOVA as a test on this new set of data. This test would also allow me to see whether there was a significant difference over the discrete time blocks.

5.7.2 ANOVA on Interval Averages

I used a repeated measures ANOVA on 15 time intervals. I wanted to see whether there was a relationship between time, feedback (either mirror-feedback or av-feedback), or a combination of the two. It was found that there is not a significant difference over time, where $F(14,6) = 0.759$, $p = 0.69$, nor is there a significant difference between AV-Feedback and Mirror-Feedback, where $F(1,19) = 1.34$, $p = 0.26$. Further to this, there did not appear to be a significant difference at the relationship between interval and time either, such that $F(14,6) = 0.60$, $p = 0.80$.

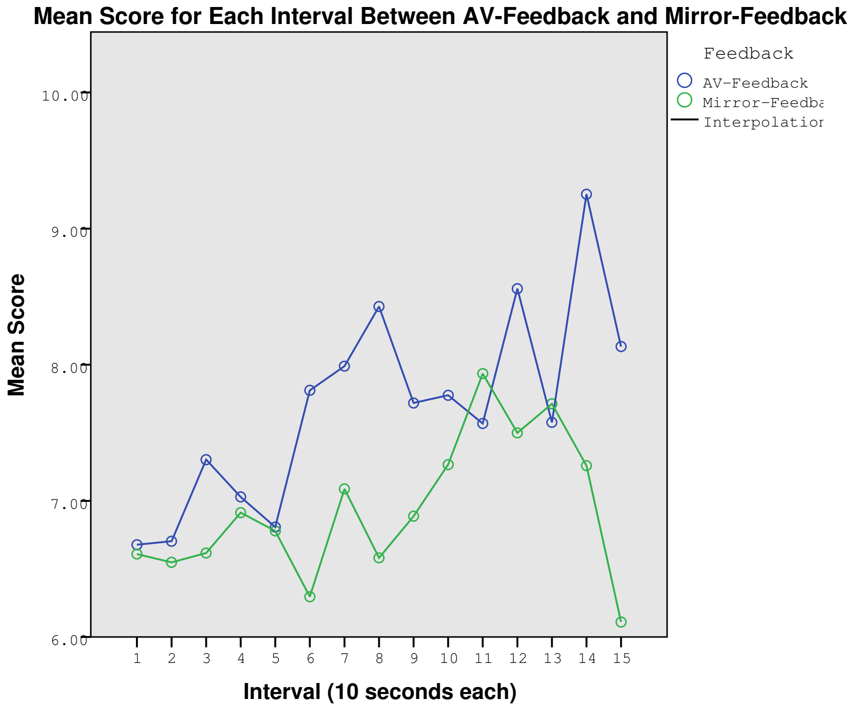


Figure 28: Average score difference between participants over time, when comparing av-feedback to mirror-feedback

After running these tests, I thought it would be still possible to run one last test on the data to see whether there would be a significant difference between the types of feedback. I tried a Generalised Linear Mixed Model with Random Effects. This test allowed me to have random effects for participant's as well as for patterns used in the experiment.

5.7.3 Mixed Generalised Linear Model on Interval Averages

The Generalised Linear Mixed Model with Random Effects, yielded a significant relationship between av-feedback and mirror-feedback, such that $p = 0.001$. Now, I have not included degrees of freedom, because there is currently a debate in statistics about whether degrees of freedom is a meaningful concept for mixed models (Winter, 2011). However, there did not appear to be a significant difference over time, such that $p = 0.55$. The same is true for any relationship between interval and feedback, such that, $p = 0.87$. For this test I placed participants and pattern numbers down as random effects. The fixed effects were feedback, and interval, as well as an interaction effect for interval * feedback. Score was the dependent variable.

Now, it appears that this test did yield significance with feedback, however, upon checking the residuals to test whether the model was valid, I discovered that the model in fact did not fit the data. The variance with the model is shown in Figure 29. Therefore, it is not valid to say that there is a true significant relationship between av-feedback and mirror-feedback.

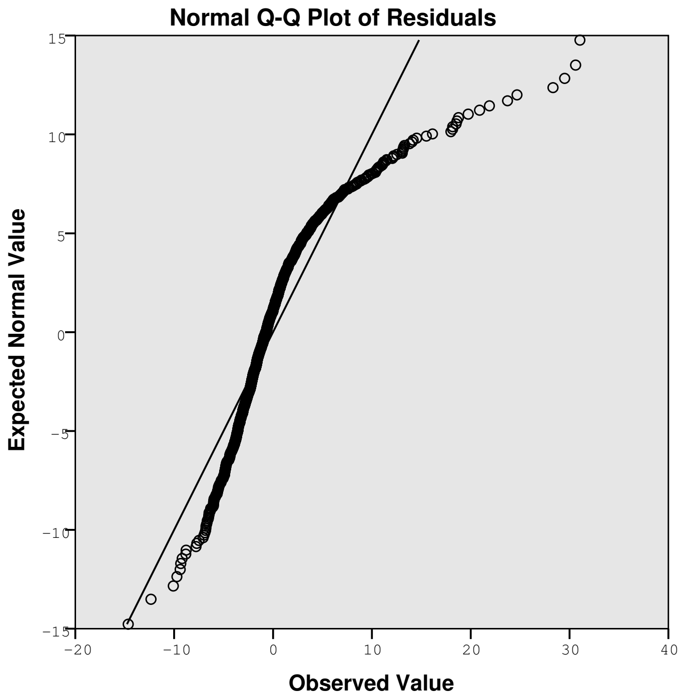


Figure 29: Mixed Generalised Linear Model QQ Plot for Scores

At this point in the data analysis, I decided to try a different form of measurement. Due to the fact that I recorded each pattern was it was performed by each participant, as well as the pattern they were attempting to perfect at the time, I was able to create a measure that calculates the distance away from the idealised path for every poi data point recorded. I took this data and aggregated the values, just like I did in the first analysis that I did on scores.

5.7.4 Paired Sample T-Test on Distance Averages

The results of the paired sample t-test on total average distance revealed that there is not a significant difference between the distances, such that T(19) = -0.46, p = 0.65. Ideally, what would have been shown was that the average distance away from the ideal would be significantly smaller on the AV-Feedback condition than with the Mirror-Feedback condition.

Table 2: Average Distance Comparison

Paired Samples Statistics				
	Mean	N	Std. Deviation	Std. Error Mean
AV Feedback	36.76	20	6.81	1.52
Mirror Feedback	38.08	20	7.74	1.73

The average distance difference when comparing AV-Feedback to Mirror-Feedback graph indicates there is a wide variability in standard deviation across participants, and thus the relative skill level for participants was not likely consistent. This is illustrated in figure 30.

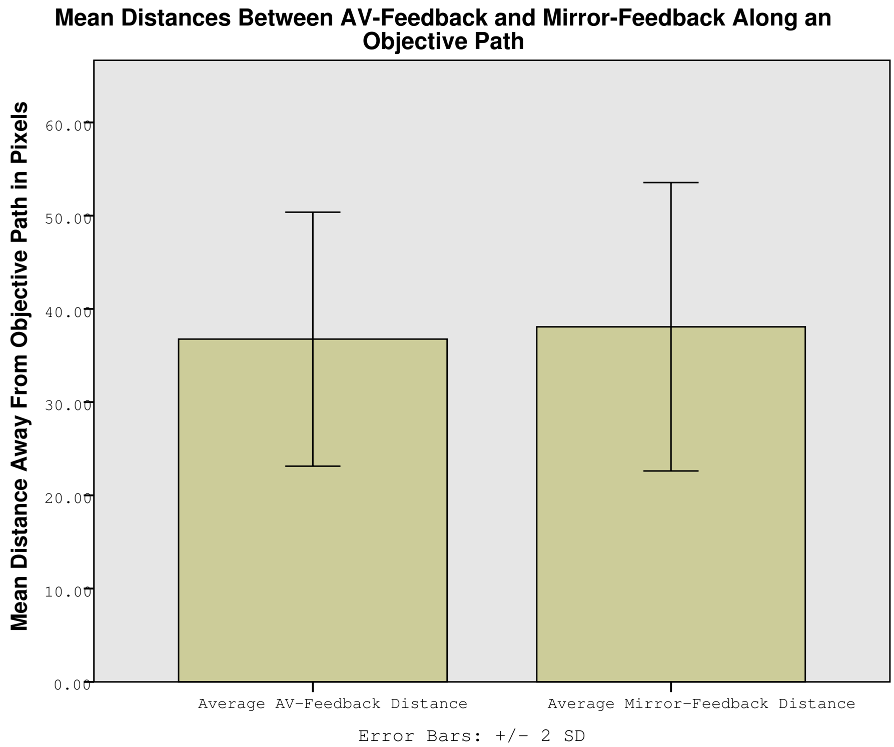


Figure 30: Average distance difference when comparing AV-Feedback to Mirror-Feedback

5.7.5 Heat Graphs and its Interpretation

At this point in my analysis, I decided to move onto an more interpretive option. This lead me to generate heat graphs from the data. From the recorded data, it is also possible to generate the heat graphs for each participant, and I have picked 4 sample images to illustrate this feature of the program. This type of data is useful as it indicates problem areas where participants need to improve upon in their patterns. Moreover, this type of information can be used to determine simple mistakes as well as problem areas of a pattern that a participant is having. The way to interpret these images is as follows. Each circle outline, the centre of which represents a recorded data point. The size of the circle was chosen to represent possible margin of error, but should not be used as a decisive indicator of variance. The ideal path that the object manipulator was to travel their object along is represented by the blue markers and the connecting blue lines between them.

I will first compare the pattern number 4, one from a av-feedback condition and one from a mirror-feedback condition. The patterns are from different participants, so while there does appear to be a clear difference between patterns, this more indicates the difference in the object manipulator than in av-feedback or mirror-feedback conditions. In this image, the manipulator was instructed to swing the point to the uppermost point on the left, and then have the poi momentarily stall in that position, before the manipulator pulls the poi back along the path it just travelled along. Next the manipulator would swing it to the opposite side, and repeat the stall then pull back process. At that point the manipulator would be performing a kind of penduluming motion.

If one looks at the following mirror-feedback Figure 31, it should be clear that the pattern performed is rather messy, when compared to the pattern path from checkpoint to checkpoint. It seems that fairly often, the object manipulator would be unable to stall the poi at the appropriate position and as a consequence, the poi would continue in its motion outside of the pattern area. This would suggest that the performer needs to work on their stall points.

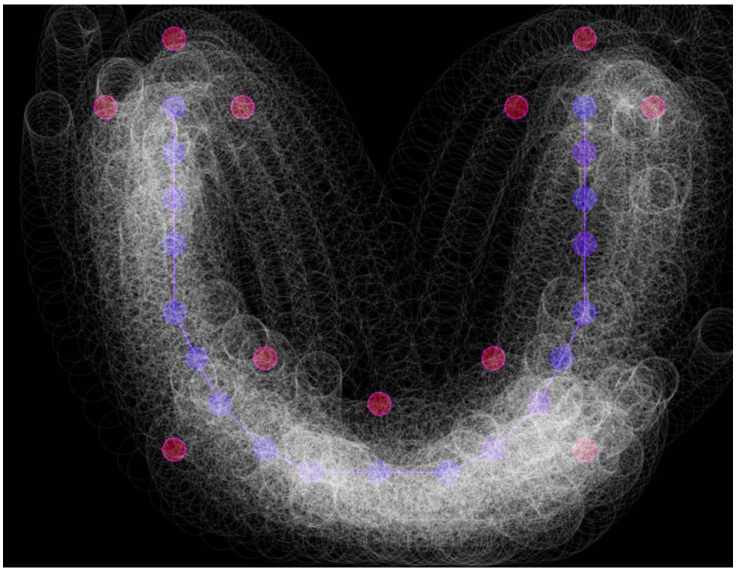


Figure 31: Pattern 4 Mirror Feedback

By contrast, look at the following image Figure 32 of the same pattern, but performed by a different object manipulator. In this pattern it should be fairly clear that the performer consistently kept the poi on the path that was intentionally designed. However, even in this representation, one can see that the trajectory which the poi travelled along was occasionally to the left and right of the ideal trajectory.

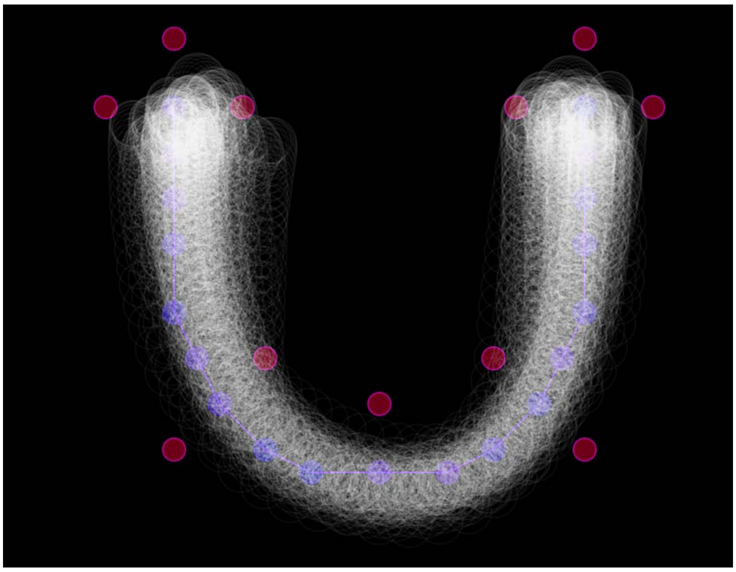


Figure 32: Pattern 4 Feedback

From those two images, it is clear that there is a great difference between the two manipulators, insofar as their ability to consistently repeat a pattern is concerned. Stalling the poi does take time to learn, and it is by no means a skill one picks up in an afternoon. It would be best to now move onto the next set of images. These heatgraphs are like the previous two, except they are of a different pattern.

In the following pattern, the manipulator was required to swing the poi with arms extended and then pause the arm at the top and bottom positions of the pattern. By pausing the arm, the poi would still maintain its velocity, but still being bound by the tether, the poi would make a smaller circle before the arm continues its fully extended movement.

Now, in Figure 33, it can be seen that in the lower middle of the image that the intersection from the inner circle is not directly in the middle of the image. This indicates that the manipulator began moving their arm too early in the lower inner circle. A way to improve this would be for the manipulator to a little later in relation to the poi position. In contrast, if one looks at the top, one will see that there is a fairly symmetrical intersect, thus showing that the pause time and position were fairly close to the ideal. It should be noted that there is a slight pull towards the right, which would indicate that the manipulator should wait a fraction more time.

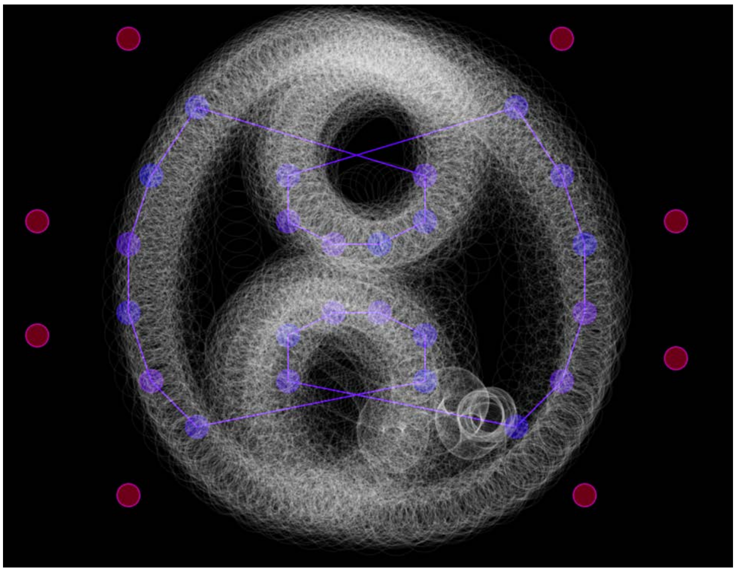


Figure 33: Pattern 3 Feedback

In Figure 34, the manipulator shows strong movements with few errors away from the path. The intersect at the top is slightly to the left, which indicates that they are not pausing long enough at the top. The bottom intersect seems quite consistent as well as symmetrical, which indicates that the manipulator waited a near ideal amount of time.

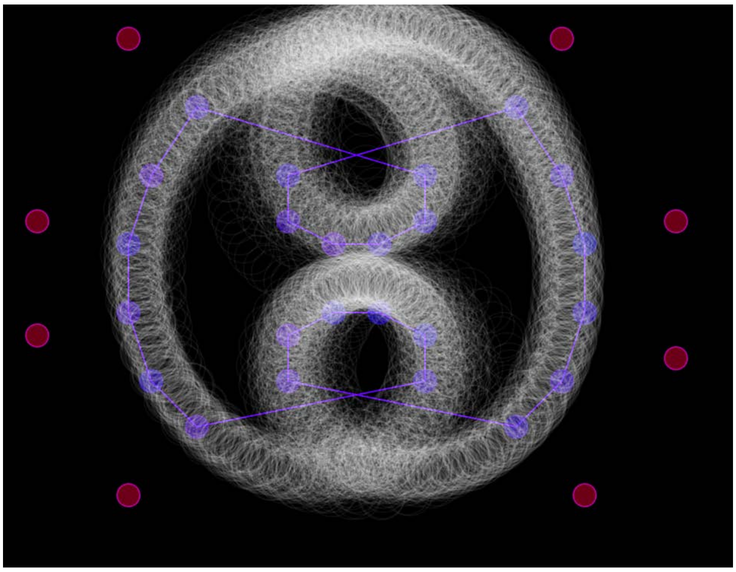


Figure 34: Pattern 3 Mirror Feedback

From the comparison of figures, it is easy to compare them against each other, which could allow in the future for comparisons over multiple visits. It is also a useful form to indicate persistent problems that the manipulator man not be aware of while performing the pattern.

Now, in the analysis, I also recorded data from a survey that all participants took. In this survey was a Game Engagement Questionnaire that measures engagement and flow state.

5.7.6 Survey Results

The Game Engagement Questionnaire survey was conducted for both the av-feedback and for the mirror-feedback condition. It was found that the overall mean of av-feedback was significantly better than the overall mean of mirror-feedback, with $T(19) = 3.55$, $p = .002$ for Engagement. Furthermore, a subset of the questionnaire looked at flow-state questions, and within that, av-feedback is also significantly better than the mean for mirror-feedback, where $T(19) = 4.28$, $p = .00$.

In Figure 36, it is shown that there a difference between engagement for av-feedback and mirror-feedback conditions.

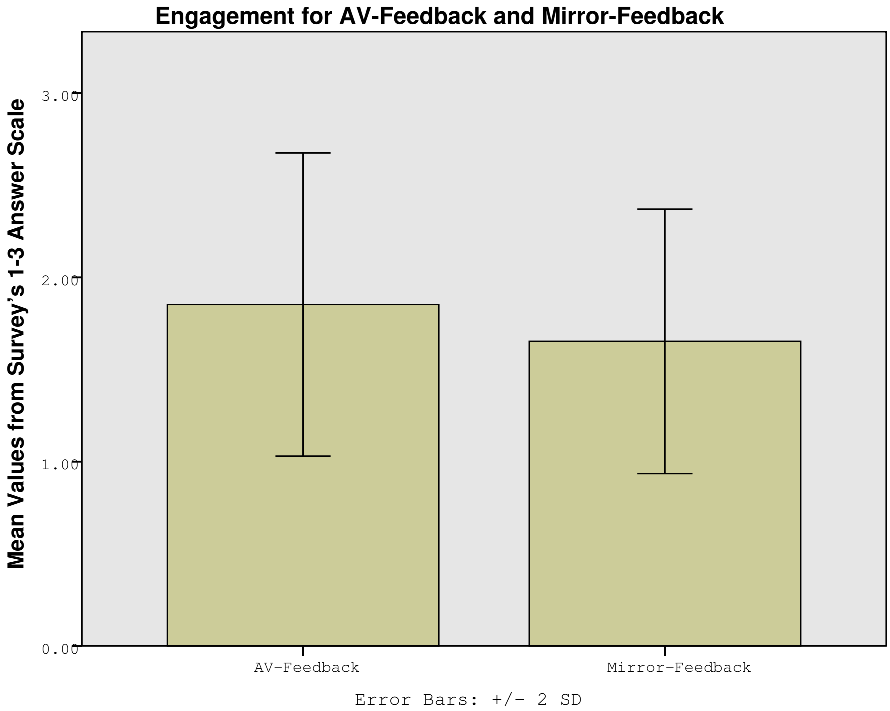


Figure 35: Engagement

In Figure 36, it is shown that there a difference between flow state for av-feedback and mirror-feedback conditions.

Figure 36: Flow

Finally, I thought it would be useful to consider some of the qualitative results.

5.7.7 Observational and Survey Question Data

In this section I describe useful observations made as participants went through the experiment. These observations could be applied to future experimental design, or could be helpful in determining areas of improvement for the feedback application.

It was noticed that only participants that had done similar patterns before knew to keep their arm along a plane close to their body. Participants with less experience would place their arm further in front of them, thus reducing the total arm extension length for the required patterns. In general, in order to maintain good form, one's arms ought to be kept on planes that run close to the body, not far away from it, unless the intention is to make it further away.

At least one participant changed hands through the experiment. The participant mentioned this was due to fatigue. There was no explicit instruction in the experimental design to pick a particular hand, whether that be right or left, or dominant versus non-dominant. In the future this condition ought to be considered in future experimental design.

All of the participants took breaks where they stopped spinning the poi. This was either due to fatigue or due to being off relative to the pattern they ought to have been practising.

Moreover, the position chosen to take a rest was different depending on the participant.

The majority of participants said they enjoyed the av-feedback condition more than the mirror-feedback condition.

Now, in the survey, I also asked three questions which required descriptive answers. These were: "what did you like most about the system?" "What did you dislike about the system?" and "Do you have any suggestions for improvement?" I will summarise some of the answers given by these questions, and also mention some key comments that I believe will help to improve the system in the future.

- 9 participants thought the sound feedback was very helpful.
- 6 participants thought the visual feedback was very helpful.
- At least 3 mentioned that the sound was calming.
- 1 participant mentioned that it increased their competitiveness.
- 9 participants said that the feedback was helpful.
- 2 participants wanted to take the system home with them.
- 4 participants thought it didn't quite fit their body, and as such they didn't quite find the right place to stand.
- At least 2 participants thought that the feedback could be overwhelming due to the amount of errors and the size of the error indicator.
- At least 2 participants wanted more colour options, and the ability to make patterns.

5.8 Discussion

Now, I shall first consider the objectively measured data and provide an interpretation why a relationship between time and av-feedback and mirror-feedback was not found. One of the issues in designing this experiment concerned time available by participants, fatigue, and the necessary time for a learning effect to be displayed. During a trial, it was noticed that 5 minutes of continual practice per pattern left the participant feeling tired and fatiqued. It was decided that the time would be reduced to 3 minutes per pattern. However, it seems that a possible consequence of reducing the recording time to 3 minutes per pattern, was that we simply did not allow enough time for a participant to improve.

And I believe this is reasonable. For 1, the patterns given to the participants were not classed as basic patterns. Rather, the patterns would be classed as intermediate to advanced, and as such, the patterns may take some time to show signs of improvement.

Another possibility as to why av-feedback and mirror-feedback did not show a significance difference could be because of time, and it also could be because participants required more directed forms of feedback. During the experiment, it was noted that at times, the participants seemed overwhelmed by the sheer amount of feedback provided to them. It stands to reason that there may be a prerequisite amount of time needed to incorporate the feedback so that it's cognitively useful.

The data shows that from the Game Engagement Questionnaire, that the feedback training was preferred over mirror-feedback. Now, because participants were significantly more engaged using the feedback training, it stands to reason that they would spend more time using it than the more traditional mirror-feedback. Furthermore, the more time poi spinners practice, the better they will become. Thus having a device that engages poi spinners to a greater degree than the more traditional mirror training, is a great advantage to poi spinners.

Given the results and the interpretation for them, a few general conclusions can be drawn. I will list these below.

Fatigue is a major issue in these types of studies. It is generally understood that the endurance ability of seasoned professionals is greater than novices, but in order for the system to cater to novices, there needs to be greater variability of patterns over a short duration. This will result in move dynamic movements that cause less strain and fatigue over time. Moreover, participants need to be given many breaks.

The generalisability of pattern difficulty level is extremely hard to gauge. Some participants from observations found some patterns much easier than others, while others found the opposite. In this case, a theory of pattern difficulty may need to be constructed, based on the number of movement concepts used to construct each pattern. It may also be possible to infer a theory based on a very large sample of patterns over many participants. This data could then be used to refine the information presented to the artist.

Some more refined measures ought to be established that quantify improvement over time. It is unclear whether successful checkpoint hits can yield the information that one wishes to be able to infer. This is echoed by one of the comments from the participants. The participant stated that measuring system is too strict, such that one error results in losing the total count. Moreover, the checkpoints simple act as measurement regions, but are not continuous measures over the whole pattern. It seems reasonable that in order to obtain more accurate measurements, one ought to measure continuously over the whole pattern. One way that one may achieve this is through having a pattern that is scaled the size of a participant's arm and object length, and measuring the distance away from the closest objective point on the ideal path. One could also infer distance travelled over time, and consider both the relative speed of the poi or object being manipulated, and the maximal and minimal distances in discrete spatial locations over time.

Participants need to either spend a lot longer with the training system in order for a learning effect to be visible. One way to achieve this may be to give the system to participants to take home with them. In that case, the participants could use the system at their leisure, and be in an environment they feel most comfortable. They would also be able to use the system over a prolonged period of time this way. Another option would be to get the same participant to come to an experimental environment at the University over many visits. This has the advanced of being able to control for possible confounding variables, but at the same time, would be less convenient for the participants.

The game engagement questionnaire proved to be a useful way to ascertain engagement and flow. However, some of the participants asked about the relevance of some of the questions in the survey. Upon investigating those questions, it is clear that they are more suited to first person shooter video games, and possibly not as well suited to games where the objectives are more abstract or based in geometry.

One of the issues encountered was that some participants did not realise how far their arms were held out in front of their bodies. This is a problem with the fact that the system only measures horizontal and vertical coordinates. If it could measure coordinates in the z axis, then a sense of depth could be visually indicated on screen. One way to solve this could also be to use a Microsoft Kinect camera, because it is a depth sensor.

6 Conclusion

In this dissertation, I have covered the development of a motion feedback training system. The system has been built around geometry structures and went through two distinct software iterations. From each iteration important lessons were learned about the framework choices, and improvements were made with that new found knowledge. It was determined that in order to construct a visually fast and real-time experience that Processing was not an appropriate software environment to use. Indeed, OpenFrameworks provides such an environment, but due to its lack of documentation, makes development slower than expected. In future versions, I plan to incorporate multiple cameras, thus allowing for 3 dimensional tracking of the poi in space.

The hardware cost of the system is less than 200 New Zealand dollars. This does not include a computer to run the application, nor does it include a projector or screen to view the system. I believe it is safe to assume that users of the system have access to some kind of screen with which to view the application on, and at least the demographic I am interested in are likely to already have computers capable of running the software. However, due to the relatively low cost, the system could easily be adapted for physiotherapy, and in that respect, it has great potential for rehabilitation.

In terms of evaluation, I now believe that in order to measure object manipulation learning, that one must measure participants over a long course of time. This is because from the results, there is no clear indication of improvement over the short recorded time per pattern (150 seconds).

7 Recommendations for Future Work

In this section I suggest research applications and recommend further research for the work presented in this thesis.

From the results and the discussion sections, it is fairly clear that further research is required to establish trends and significance of the objective poi positions over time. Furthermore, more research is required to establish a better test of consistency with respect to a user's own physical movements. One way to do this would be to establish a poi path history. Over repetitions, the path could be reduced in its width. As the path reduces in width, the challenge to stay within the path's boundaries becomes naturally more difficult. It may be possible to establish a measurement of the path decrease in boundary width over time.

It is also quite clear that one of the problems with the research was that the measurement time per pattern was insufficient to measure a proper learning effect over time. I outlined the reasons why this should be the case in the discussion section. One possible solution to this problem, would be for future studies interested in training to get participants to come in over multiple days. This would allow one to consider improvement over a stretch of time, and that would likely be more beneficial, and closer to the real-world training techniques employed by artists and object manipulators.

Another direction in which this software could be considered in for rehabilitation. Consider the following scenario as a proof of concept for this direction. Assume a person has sustained a shoulder injury, and has gone to a physiotherapist for help. The physiotherapist suggests and shows a series of movements that the person with the shoulder injury is to perform at regular intervals throughout the week. Now, while the physiotherapist has instructed the injured person what to do, the likelihood that the person forgets the details of some of the movements is quite high. Moreover, when the person goes home, there is no way for the person to check what the person is doing is in fact the correct movements. Part of this could be that the injured person doesn't have the same conceptual understanding of the body that the physiotherapist does, and as such, the injured person is unable to focus on the parts of the body that the physiotherapist needs the injured person to focus on.

From this scenario, it seems that there are two points which the feedback system in this thesis could address. The first concerns itself with being used as a memory aid for the injured person. So, if the movements could be recorded for the person, then the person would be in a better position to remember what movements the person is to perform. However, simply reviewing a recording isn't sufficient to learn proper form, and to make sure that the movements are being done correctly. The feedback system could be used to record the movements given by the physio, while the injured person is seeing the physio. Those movements would thus be recorded relative to the injured person.

The second issue is that even if there is a recording of the movements, the injured person gets no feedback once they leave the physio's office. A solution to this could work like this. The person takes home with them a version of the feedback system discussed in this thesis, plugs it into a display device (such as a TV), and then has to mimic the movements that were recorded earlier. The system could provide automated feedback about how well the injured person is doing with respect to the previously recorded movements, and those results could be sent back to the physio for the physio to review the progress of the injured person.

Another area where it would be quite useful to spend extra time is to try to track different kinds of objects. The beginnings of this has already started from the field testing I did. However, it would be more valuable to do object detection tests, and develop a library of tracking techniques to for the different kinds of objects.

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